AGE-RELATED DIFFERENCES IN VERBAL, VISUAL AND SPATIAL MEMORY: The Same or Different?

Thesis submitted by

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DECLARATION ON ETHICS

The research presented and reported in this thesis was conducted within the guidelines for research ethics outlined in the *National Statement on Ethics Conduct in Research Involving Human* (1999), the *Joint NHMRC/AVCC Statement and Guidelines on Research Practice* (1997), the *James Cook University Policy on Experimentation Ethics. Standard Practices and Guidelines* (2001), and the *James Cook University Statement and Guidelines on Research Practice* (2001). The proposed research methodology received clearance from the James Cook University Experimentation Ethics Review Committee (Approval numbers: H1718, H1947 and 2137).

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ABSTRACT

Working memory comprises a number of components, each responsible for the processing of different types of information. The phonological loop is responsible for processing verbal information while the visuo-spatial sketchpad is responsible for processing visual and spatial information. Age-related differences in verbal working memory are well documented with older adults consistently shown to have shorter memory spans than younger adults. Declines in spatial memory have also been reported. The data for visual memory performance however is less clear, with some researchers reporting decline across the adult lifespan and others reporting no difference. The purpose of the current thesis was to examine performance on a number of verbal, visual and spatial memory tasks in an effort to determine whether each type of memory declined with increased age and if so, whether they were affected by age to the same extent. Three studies were conducted to achieve these aims.

The first study explored the role of articulatory suppression, which has been shown to disrupt performance on verbal memory tasks; the effect on visual and spatial memory tasks is not so clear however. Fifty university undergraduates (12 men, 38 women) aged between 18 and 53 years (*M* = 24.38; *SD* = 8.62) completed verbal, visual and spatial memory tasks of differing memory set sizes under suppression and no suppression conditions in Study One. Results show that performance on all the tasks at each set size was significantly affected by concurrent verbal suppression. It was concluded that articulatory suppression prevents participants from verbally encoding visual and spatial stimuli, leaving them to rely on purely visual or spatial representations. As a result articulatory suppression may provide researchers with an effective means to examine these types of memory with minimal contributions from the verbal system.

Study Two examined the reliability and validity of nine working memory tasks. One hundred and two first and second year psychology undergraduates aged between 18 and 56 years (*M* = 23.96, *SD* = 9.78) completed three verbal, three visual and three spatial working memory tasks. Seventy-three of these participants returned for retesting 14 days later. Results show that the test-retest reliability of the tasks was adequate to good with reliabilities ranging from 0.51 for letter orientation to 0.89 for the arithmetic task. Three factors, interpreted as verbal, visual and spatial factors, emerged from the data, accounting for a total of 58.8% of the variance. The tasks, with the exception of letter orientation, appeared to be reliable and valid indicators of the constructs they were designed to measure and were therefore used in Study Three of the current thesis. However, it is suggested that the psychometric properties of the tasks be examined in additional and preferably larger samples and using a smaller memory set size and different age groups.

Study Three examined age-related differences in verbal, visual and spatial memory using all of the tasks from Study Two except for letter orientation.

Letter orientation was replaced with a letter location memory task, which was similar in design to the dot memory task used in Study Two. Two hundred and one university undergraduates and community dwelling residents aged between 18 and 80 years, 139 females and 62 males (*M* = 44.95; *SD* = 21.08) completed three processing speed tasks, three verbal, three visual and three spatial memory tasks. Results of a 3 (task: verbal, visual, spatial) × 3 (age group: young middle, older) mixed ANOVA with Bonferroni corrected comparisons revealed that there were no significant differences between young and middle aged adults performance on the verbal, visual or spatial memory tasks. Significant differences were revealed between the young and older adults' verbal and spatial memory performance but not for visual memory performance. The differences between the middle and older age groups' verbal, visual and spatial memory scores were significantly different.

The relationship between age and each type of memory was examined using a series of regression analyses. The first, using age as a predictor of each type of memory, showed that age explained a significant amount of the variance in verbal (11%), visual (3%), and spatial (16%) memory. After controlling for processing speed, the amount of age related variance on each type of memory decreased (verbal 5%, visual 0.08% and spatial 9%). Speed acted as a partial mediator of verbal memory variance and a full mediator of visual memory variance but not of spatial memory variance. Regression models using age, number of medications and processing speed explained a significant 15% of the variance in verbal memory, 17% of the visual memory variance and 17% of the spatial memory variance. Age made significant contributions to verbal and spatial memory variance but not to visual memory variance. Processing speed made significant contributions to the variance in verbal and visual memory but not in spatial memory. The number of medications taken per day was the strongest contributor to visual memory variance.

Because the *n*-back tasks used in this study may have been tapping central executive processes, further models were examined using these tasks as a central executive variable along with age, number of medications, and processing speed. The results of these analyses revealed that the model explained a significant 36% of the variance in verbal memory, 32% of the visual memory variance and 28% of the spatial memory variance. The central executive variable was the strongest contributor to the variance in verbal memory (25%) and visual memory (11%); however age remained the strongest contributor to spatial memory variance (12%). Processing speed no longer made a significant contribution to verbal memory variance when the central executive variable was included in the model.

It was concluded that verbal, visual and spatial memories do decline with age but only after middle age; there appears to be little difference between young and middle aged adults. It was also concluded that verbal, visual and spatial memories are differentially affected by age with age explaining more of the variance in spatial memory than in verbal and visual memory. Age does make a significant contribution to verbal memory variance but it is not a significant predictor of visual memory performance. Hence, the decline in visual memory performance after middle age is not age-related but appears to be related to other variables such as the number of medications a person takes each day and to the efficiency of central executive functioning. The relationship between verbal, visual and spatial memory performance and processing speed is also not the same across the lifespan, with processing speed mediating the variance between age and verbal and visual memory, but not spatial memory. Finally, it appears that the central executive plays an important role in performance levels on each of the different types of memory but not to the same extent in each subsystem.

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1.1 Introduction

Life expectancy for non-Indigenous Australians in 1999 was 76.2 years for males and 81.8 years for females (Australian Bureau of Statistics [ABS], 2000). These figures are consistent with those from a number of other Western nations including, the United States of America (USA), France, Canada, the United Kingdom, and New Zealand. Globally the figure is approximately 67 years and rising (Riley, 2001). Life expectancy for Indigenous Australians is lower than for non-Indigenous Australians, 56 years for males and 76 years for females (ABS, 2000). Compare these figures with those of the 1800s when the average lifespan at birth was only about 30 years (Riley, 2001). Increases in life expectancy can be attributed to improvements in a number of areas, including: public health, medicine, wealth and income, nutrition, behaviour, and education (Riley, 2001). People are living longer and as a consequence the world's population is becoming older as the birth rate declines in most countries of the world.

The fact that people are living longer is of course good news. However, a number of questions about potential problems that people may face as a result of living longer also come to the fore. Such problems could be of a personal, social, medical, or economical nature (Stokes, 1992). Further problems could be related to cognitive functioning and indeed there is a growing extant literature reporting how cognitive processes are affected by age. Some researchers have focused on increased knowledge and experience that comes with increased age, however, more attention has been given to declines that occur in cognitive ability (Park, 2000) including declines in memory functioning.

How often do we hear older people declare that their memory is not what it used to be? Our ability to remember indeed does deteriorate as we grow older. There are, of course, a number of different types of memory (for example, sensory, semantic, short-term, working, long-term) that may, or may not, be affected by age or that may be affected to differing extents. For instance, sensory (Walsh & Thompson, 1978) and semantic (Hultsch & Dixon, 1990) memory have been shown to be affected by increased age, but not to the same extent as working memory, which is particularly sensitive to changes with increasing age (Stokes, 1992).

Working memory is a memory system that enables the simultaneous storage and processing of information and which is important for everyday cognitive functioning. It enables us to perform complex cognitive tasks such as problem solving and reasoning. It has also been found to be important for everyday tasks such as making decisions of a medical nature, including remembering to take medications (Park, Morrell, Frieske, & Kincaid, 1992). Baddeley and Hitch (1974) developed a model of working memory (described in detail in Chapter 2) that comprised a domain-general controlling system referred to as the central executive and two domain-specific slave systems – the phonological loop and the visuo-spatial sketchpad. The phonological loop is responsible for verbal-based information while the sketchpad is responsible for both visual and spatial information. While age-related decline in the verbal component of the working memory model has been well studied, there are a number of inconsistencies and methodological problems in research examining age differences in visual and spatial memory. The current thesis aims to address some of these issues. But, before the aims and significance of the present thesis are discussed it is important to provide definitions for some important concepts that will be used throughout the current thesis.

1.2 Definitions

1.2.1 Working memory

Throughout this dissertation working memory will be defined as a memory system that provides the ability to simultaneously maintain and process information. This definition also allows information to be stored for a brief period of time. Information may be verbal, visual or spatial in nature, with each different type of memory likely to involve activation of different areas of the brain (Smith & Jonides, 1997). There are likely to be other types of information that can be processed by working memory, for example temporal, source, or tactile; the current thesis is however only concerned with verbal, visual and spatial memory.

A working memory task is a task that requires the storage and manipulation of information. For example, mental arithmetic requires both the storage and manipulation of information and therefore requires working memory functioning (see for example, Oberauer, Demmrich, Mayr, & Kliegl, 2001). This type of task can be distinguished from storage only tasks. The difference between these two types of tasks is an important one. Storage only tasks are often referred to as short-term memory tasks and only tap phonological loop and visuo-spatial sketchpad functioning. Storage plus manipulation tasks, on the other hand, presumably require additional central executive processes (Miyake, Friedman, Rettinger, Shah, & Hegarty, 2001; Oberauer, Süss, Schulze, & Wittman, 2000). It is also thought that the distinction between the two types of tasks is more pronounced for verbal working memory than for visual or spatial memory. As a consequence, visual and spatial short-term tasks may be equivalent to visual and spatial working memory tasks; both are thought to require central executive processes.

1.2.2 Age

One of the problems faced by cognitive aging researchers is that providing a clear definition for age is difficult. Different researchers define age in different ways (Kermis, 1984). Chronological age, the most common measure of age, refers to the number of years from a person's date of birth (Stuart-Hamilton, 1994). Another form of age is social age, or how one is expected to act at a specific chronological age. Age can also be defined in terms of biological or psychological factors. Biological age refers to the actual physical state of one's body in comparison to standards for that chronological age, while psychological age refers to personality development and to the degree of cognitive competence a person maintains across the lifespan (Stuart-Hamilton, 1994).

For present purposes age will be defined, and measured, as the number of years from birth, or chronological age. While it is acknowledged that chronological age does not tell us much about how an individual person may be functioning at a particular age, it allows us to gauge how a group of people within a particular age range perform on a number of memory tasks and how performance may change as a result of increased age. Moreover, the different types of age are not totally independent; cognitive functioning can be affected by a person's physical and psychological wellbeing (Stuart-Hamilton, 1994).

It is also acknowledged that the boundaries for different age groups are often blurred, inconsistent, and arbitrary; there is no clear cut distinction between being considered young and being considered middle aged for example (Lachman, 2004). Furthermore, different individuals have different views on at what age one becomes middle aged or old. A person in their late 60s, who is physically and psychologically healthy, may consider themselves to be middle aged, not old aged. That being said, it is necessary when conducting research that clear boundaries be set when defining different age groups. Therefore, the age groups used in the current thesis were based on those that have been previously commonly used in the cognitive aging literature (see for example, Meguro, et al., 2000; Salthouse, 1996b). Participants between the ages of 18 and 39 years formed the young age group, those between 40 and 59 years the middle age group, and those between 60 and 80 years the older age group.

Because the number of older adults living beyond 75 years of age is increasing, some researchers often distinguish between the "young-old" (65 to 74 years) and the "old-old" (75 years and above) (Stokes, 1992). No such distinction was made here and all participants above 60 years of age were considered part of the old age group.

1.3 Aims and Significance

There are very few studies that have directly compared age-related differences in verbal, visual and spatial memory. The main aim of the present thesis was to examine whether the verbal, visual and spatial components of working memory all decline with age and, if so, to examine whether that decline is the same or different across the different types of memory. Three studies were conducted to achieve this aim. The first examined how verbal, visual and spatial working memories were affected by articulatory suppression. Verbal, visual and spatial working memories were then assessed using multiple tasks designed to measure each type of memory with minimal contribution from the other systems. In other words, the reliability and validity of each of the tasks was examined to ensure that they were measuring the constructs they had been designed to measure. Finally, an examination of the nature of change as a function of chronological age for each type of working memory was undertaken to determine whether they all changed with age and whether they changed at the same, or different, rates.

Our population is aging and it is important that researchers attempt to gain an understanding of any changes that may occur as a function of age and how these changes may affect older adult’s daily lives. Understanding the changes that may, or may not, occur in working memory processes can be of benefit not only to cognitive aging researchers, but also to older people themselves. Such research may help guide decisions made by policy makers in a direction that would be of greatest benefit to older adults. It would also add valuable information to existing knowledge about age-related changes in cognitive functioning.

1.4 Research Overview

Each of the three studies that make up the current thesis was based on the need to undertake a number of steps before the overall aims of the thesis could be addressed. Each study was developed around individual research questions which will now be discussed.

1.4.1 Research questions

Articulatory suppression is a technique (see Chapter 4) that is often used by cognitive researchers to help minimise verbal encoding strategies in visual and spatial memory tasks. However, there is no clear evidence of the effects articulatory suppression has on performance on visual and spatial working memory tasks. A number of researchers have found no impairment in performance with the inclusion of a verbal suppression task (see for example Pickering, Gathercole, Hall, & Lloyd, 2001), while others (Miles, Morgan, Milne, & Morris, 1996) have found that performance is impaired. If articulatory suppression does impair performance on visual and spatial tasks then one could assume that participants are using verbal labels in an attempt to remember these stimuli. Performance on these tasks without suppression may involve phonological loop functioning as well as visuo-spatial sketchpad functioning. As a result of the inconsistencies in the previous literature, and because the tasks used in this thesis are quite different from those that have been used in previous research, Study One was designed to answer the question: What effect does articulatory suppression have on verbal, visual and spatial memory performance.

Study Two was designed to determine the reliability and validity of the nine tasks designed to assess verbal, visual and spatial working memory. These tasks were then used in Study Three which asked: Do verbal, visual and spatial memory change with increased age? And if so, is the rate of change in each of the different types of memory equivalent or different?

1.5 Limits of the Research

The current thesis looks at memory differences in physically healthy, non-demented participants only. The memory loss that occurs with dementia may not be the result of the same mechanisms that underlie memory loss that accompanies normal aging. Research has shown that there may be a difference between the mediation of variables in dementia-related memory loss as compared to normal aging. For example Sliwinski and Buschke (1997) found that statically controlling for processing speed significantly weakened age-related variance in a number of memory tasks in a sample of non-demented participants. However, they found no significant reduction in dementia-related memory decline when controlling for processing speed, leading to the conclusion that processing speed is not important in the memory loss that accompanies dementia (see also Luszcz & Bryan, 1999).

1.6 Thesis Outline

An important concept for present purposes is working memory; hence, Chapter 2 provides an introduction to a model of working memory that provided the theoretical impetus for this dissertation. Behavioural, neuropsychological, and neurophysiological data supporting the multicomponent nature of the model is reviewed.

Chapter 3 provides a broad overview of the literature on working memory and cognitive aging. The chapter defines cognitive aging and provides evidence that shows how the speed at which one processes information and working memory play important roles in performance on a variety of cognitive tasks. The literature on working memory and aging from behavioural and neurophysiological perspectives is reviewed. It shows that although there is considerable evidence for an age-related decline in verbal working memory, and some evidence for age-related change in spatial memory, there is little research examining changes in visual working memory. It is also unclear from previous research whether verbal, visual and spatial memories change at the same, or differential rates.

Chapter 4 is organised with a review of literature highlighting inconsistencies as to the effects of articulatory suppression on visual and spatial memory performance. The review is followed by details of the methodology adopted to undertake Study One, which was designed to examine the effect of articulatory suppression on verbal, visual and spatial working memory. The results of the study are presented followed by a discussion of the results.

Chapter 5 provides a discussion on the need to use reliable and valid measures when examining hypothetical constructs like working memory. This is followed by the details of Study Two. Study Two was designed to determine whether the tasks designed to measure verbal, visual, spatial working memory in the present thesis are indeed reliable and valid measures of these constructs. The results of Study Three, which examined age-related changes in verbal, visual and spatial memory, are reported in Chapter 6. The issue of differential or equivalent rates of decline is also addressed in Chapter 6. Finally, Chapter 7 provides a general discussion of the results of the three studies reported in this thesis and what they mean in relation to the aims of the thesis and to the study of working memory and aging in general. Limitations of the research and implications of the results of the four studies are discussed and some future research directions are suggested. But first, a detailed discussion of working memory is provided in Chapter 2.

CHAPTER 2

A Model of Working Memory

2.1 Chapter Introduction

Humans have the ability to store and subsequently retrieve information that is acquired from the environment via our senses. This ability is referred to as human memory and is fundamental to our very existence. Groome et al. (1999, p. 96) captured the importance of human memory when they stated "In a sense it can be said that our very identity relies on an intact memory, and the ability to remember who we are and the things that we have done." Traditionally models of memory distinguish between sensory memory, short-term memory, and long-term memory (Atkinson & Shiffrin, 1968). Sensory memory refers to the very brief retention of sensory information such as auditory, visual, tactile, olfactory, taste information. Traces from sensory memory will decay very quickly (in milliseconds) unless the information is attended to. Long-term memory is memory for events that have been maintained over a long period of time, days, weeks, or years. Short-term memory, on the other hand, refers to a memory system that can hold a small amount of information, of which we are consciously aware, for a short period of time (seconds to minutes) (Atkinson & Shiffrin, 1968).

William James (1952) originally distinguished between short-term and long-term memory, although he used the terms "primary" and "secondary" memory, terms that are still used today. Evidence for distinct short-term and long-term stores was provided by research with brain damaged patients who had impaired long-term memory but intact short-term memory (see for example, Baddeley & Warrington, 1970) and those with impaired short-term memory but intact long-term memory (Warrington & Shallice, 1969). One of the earliest models to highlight the distinction between the different memory stores was the modal model proposed by Atkinson and Shiffrin in 1968. The modal model posits that input is received by the sensory stores and will be transferred on to short-term storage if it is attended to. A small amount of information can be held in short-term memory by a process of rehearsal. Rehearsal will also enable the information to be passed on to long-term memory. The model also allows for information loss, either by decay or interference (Goldstein, 2005). Because of the sequential structure of the modal model, the only means for sensory information to pass on to long-term memory is via the short-term store. However, as was previously mentioned, research has found that some brain damaged patients have impaired short-term memory but still retain their long-term memory (Warrington & Shallice, 1969); therefore the short-term store cannot be the only avenue to the long-term store.

In 1974 Baddeley and Hitch proposed a model of short-term memory that attempted to account for a variety of data that the modal model could not account for and to address the shortcomings of the model. For example, research by Baddeley and Hitch found that it was possible for a person to complete two tasks at the same time, reading and remembering a string of digits. According to the modal model, this should not be possible because short-term memory is limited in the amount of information it can hold at a given time. Capacity of the system would be reached by reading a passage and as a result, a person should not be able to remember the string of digits as well. At least, they should have impaired memory for the digits; however, this was not the case. Participants were able to recall all the digits. Based on these findings Baddeley and Hitch concluded that rather than being a unitary system, short-term memory likely contained a number of components that functioned separately. Baddeley and Hitch's model, referred to as the working memory model, provided the theoretical framework for the present dissertation and will be described in detail in the present chapter. Behavioural, neuropsychological, and neurophysiological data showing that working memory comprises a number of subcomponents each of which represents a specific type of memory will also be reviewed.

2.2 Working Memory

Working memory is a system that enables the temporary storage and processing of information and as such it is important for the execution of complex cognitive processes (Baddeley, 1992). According to Miyake and Shah (1999, p. 450), "Working memory is those mechanisms or processes that are involved in the control, regulation, and active maintenance of task-relevant information in the service of complex cognition." Although a number of working memory models have been proposed (e.g., Engle, et al., 1992; Jones, Farrand, Stuart, & Morris, 1995; Just & Carpenter, 1992; Macken & Jones, 1995, 2003), perhaps the most well developed and influential model is that of Baddeley and Hitch (1974). Baddeley and Hitch, and later Baddeley (1986), proposed a tripartite model that comprised a controlling system referred to as the central executive and two domain-specific, limited capacity slave systems, the phonological loop and the visuo-spatial sketchpad.

Recently, Baddeley (2000) added another component, the episodic buffer, to the model. A discussion of each of these components follows.

2.2.1 The central executive

The central executive is the least specified component of the model, apart from the recently included episodic buffer. Part of the difficulty in specifying the central executive comes from uncertainty about what it actually does (Towse & Houston-Price, 2001). What it can, or may, do, of course is related to how one defines it. For instance, some consider the central executive as a general purpose processor responsible for the processing-storage trade off found in working memory span tasks (Daneman & Carpenter, 1980). Others consider that it is important for performance on dual tasks; more resources are needed when one performs two tasks at the same time than when one performs them individually (Baddeley, Bressi, Della Sala, Logie, & Spinnler, 1991). Baddeley (1986) suggested that Norman and Shallice's Supervisory Attentional System (SAS) could act as a model for the central executive mainly because of its role as an attentional controller. As a consequence, recent attempts at understanding central executive functioning have proceeded on the assumption that it is responsible for the attentional control of the working memory system (Baddeley, 2001). The latter assumption can be seen to be related to the two previous definitions in that performance on working memory span tasks, and on dual tasks, requires attentional control.

Explorations of a range of functions, including the capacity for divided attention (Baddeley, Baddeley, Bucks, & Wilcock, 2001), focused attention

(Baddeley, Emslie, Kolodny, & Duncan, 1998), and the integration of information between the two slave systems and long-term memory (Baddeley, 1996), have been undertaken. Task switching may involve some executive capacity, however, recent work by Baddeley, Chincotta and Adlam (2001) suggests that the phonological loop may be more crucial for task switching than the central executive. Moreover, there exists some doubt as to whether task switching is distinct from dual task coordination (Hartley & Little, 2000). Indeed, it has been shown that both processes activate similar regions of the brain (Collette & Van der Linden, 2002). A further process attributed to the central executive is updating, which involves modifying the contents of working memory to incorporate incoming information (Morris & Jones, 1990). The role of the central executive in each of these different functions has led to the suggestion that the central executive may be fractionated according to function (Baddeley, 1996a; Collette & Van der Linden, 2002). It also shows that the central executive is strongly involved in the allocation and coordination of attentional resources of the working memory system.

Engle, Kane, and Tulholski (1999) also stressed the importance of controlled attention in working memory, particularly in complex working memory tasks such as the reading span task, arguing that individual differences in working memory capacity reflect individual differences in the ability to control attention. However controlled attention is not the only factor that affects the capacity limits of working memory. Capacity may also be constrained by a variety of other factors such as processing speed, lack of knowledge, similarity-based interference, and information decay (Miyake & Shah, 1999).

The lack of specification of the central executive continues to pose a problem for the working memory model. While recent neuroimaging research is providing some clarification of the processes under central executive control (for a review see Collette & Van der Linden, 2002), much more research is needed before we can clearly state the functions of the executive. However, for present purposes, the central executive will be considered a component of the working memory model responsible for enabling performance on tasks that require capacity above that available to the slave systems.

2.2.2 The phonological loop

The first slave system of Baddeley and Hitch's (1974) working memory model, the phonological loop, is the most well developed component of the model. The phonological loop is assumed to be important for learning to read and to speak, and for language comprehension. It comprises two components – the phonological store and the articulatory control process. The phonological store is responsible for holding verbal-based information for a brief period. The articulatory control process is assumed to be responsible for maintaining a small amount of verbal information in the store by a process of subvocal rehearsal (Baddeley, 1990). Auditorally presented material has direct access to the phonological store, while visually presented material needs to be recoded into phonological form by the articulatory rehearsal component before it can gain access to the store (Baddeley, 2001).

Research with patients with short-term memory deficits has provided evidence for the existence of the separate storage and rehearsal processes attributed to the phonological loop. For example, Vallar and Baddeley (1984; see also Vallar & Papagno, 1986) found impairment of the phonological store in a patient referred to as P.V. Patient P.V. had intact verbal memory for items presented visually, but impaired memory for auditory presentation. In contrast, Belleville, Peretz, and Arguin (1992) found specific impairment of the articulatory control process in a different patient, Ro.L. Ro.L had intact visuo-spatial memory, central executive functioning and phonological store. However, processes requiring articulatory control process functioning were disrupted. For example, the word-length effect was absent for both visual and auditory modalities and there was no evidence of the typical effects of articulatory suppression on subsequent memory performance.

The limited capacity of the phonological loop is reflected in performance on tasks that require participants to recall a sequence of digits or words of increasing length in order of presentation, for example, digit and word span (Torgesen, 1996). As the number of to-be-remembered items increases, items presented first are likely to fade from memory before the last item can be processed, or the processing of the later items is likely to interfere with the recall of the earlier items. The length of a sequence that can be remembered is thought to be a function of the spoken duration of the items. The time it takes to articulate each item will determine how many items will be maintained by the phonological store. Also, the longer it takes to reproduce the words at recall can affect the number of items that can be remembered (Cowan, et al., 1992). The number of items that can be maintained at any one time will also vary depending on the language being spoken, because of a difference in articulation time of words between languages (Naveh-Benjamin & Ayres, 1986). The number of items that can be correctly recalled also reflects the individual's verbal memory span, which may also be influenced by factors such as acoustic similarity, unattended speech, and articulatory suppression (Baddeley, 1996b). Indeed these factors provided the empirical impetus for the theoretical development of the phonological loop.

2.2.3 The visuo-spatial sketchpad

Development of theory related to the visuo-spatial sketchpad proceeded without the empirical underpinnings afforded the phonological loop. Most researchers conceded that a visuo-spatial system similar to the phonological loop existed, but were unclear about how it should be specified (Pearson, 2001). Researchers originally assumed that the sketchpad was responsible for the generation and manipulation of visuo-spatial images. As a result, development of the system was similar to that of models of visual imagery (Logie & Pearson, 1997). More recent research, however, suggests that the visuo-spatial sketchpad represents a multi-faceted system with both visual and spatial dimensions, each with their own separate maintenance, manipulation, and storage mechanisms (Salway & Logie, 1995). Visual and spatial information may be stored in two separate, but related components, a 'visual cache,' which is linked to the visual perception system, and an 'inner scribe,' which is linked to the planning and execution of movement in three dimensional space (Logie & Pearson,1997). Visual memory deals with an object's appearance while spatial memory deals with location or direction (Baddeley & Hitch, 1994).

Investigations into the workings of the visuo-spatial sketchpad are made particularly difficult because of the natural tendency people have to attach verbal labels to visual and spatial stimuli (Bahrick & Boucher, 1968; Washburn & Astur, 1998). If visual and spatial stimuli are being verbally encoded, then both the visuo-spatial sketchpad and the phonological loop are contributing to performance on visual and spatial tasks. One method of preventing verbal encoding on visual and spatial tasks is to use an articulatory suppression task.

Articulatory suppression, repeating a word or a syllable out loud during presentation of to-be-remembered items, interferes with the functioning of the articulatory control process (Baddeley, 1990). As was previously mentioned, the articulatory control process recodes visually presented items into phonological form, thereby allowing the items to gain access to the phonological store. Including an articulatory suppression task during the encoding stage of visual and spatial memory tasks helps prevent this recoding process from taking place. There is, however, some conjecture as to the effect of suppression on visual and spatial memory performance. Some researchers (e.g., Pickering, et al., 2001; Vandierendonck, Kemps, Fastame, & Szmalec, 2004; Vogel, Woodman, & Luck, 2001) have found that visual and spatial memory performance is not affected by a concurrent verbal task. Others (Miles, et al., 1996; Steward, 2002) have shown that articulatory suppression does impair subsequent performance on visual and spatial memory tasks. The effect of suppression on verbal, visual and spatial memories will be examined in Study One (Chapter 4) of the present dissertation.

2.2.4 The episodic buffer

Recently Baddeley (2000) added a further component to the working memory model to help account for a number of phenomena that the original model could not explain. For example, according to the original model, articulatory suppression should impair serial recall of visually presented verbal material because it prevents the items from being recoded into their phonological form. While recall is impaired by suppression it is not totally eliminated, suggesting that the material is being stored somewhere other than in the phonological store. A similar situation is found with patients who have impaired phonological memory. These patients have severely impaired memory when items are presented auditorally, but their memory span when items are presented visually increases (Baddeley, 2000). To help address these inconsistencies, Baddeley proposed another component for the model capable of storing and integrating multimodal information. The new component has been named the episodic buffer, “a limited-capacity temporary storage system that is capable of integrating information from a variety of sources” (Baddeley, 2000, p. 421). Information from the two slave systems and long-term memory can be bound into a single episodic representation. There is some recent research suggesting a role for the episodic buffer in storing integrated visual information (Baddeley & Andrade, 2000; Zimmer, Speiser, & Seidler, 2003), information about the combined feature of objects including colour, orientation, and so on.

The discussion of the episodic buffer offered here is necessarily short because the component is still in its developmental phase. As a result the component is not yet fully specified. Also, while there may be some advantages to adding another component to the existing model (for example, it enables information from the slave systems to be used in conjunction), there are also disadvantages. Perhaps the main disadvantage is that the inclusion of an extra component to account for troublesome phenomena adds to the complexity of the model. One of the appealing features of Baddeley and Hitch's model over the years has been its simplicity (Andrade, 2001).

The episodic buffer may become an important part of the working memory model once its hypothesised functions have been tested experimentally using both behavioural and neurophysiological approaches. In the interim there still remain many unanswered questions about the functioning of the original components of Baddeley and Hitch's model, especially in relation to the effects of age on verbal, visual and spatial working memories. The present thesis aims to answer some of these questions. But first, I provide a discussion of the behavioural, neuropsychological, and neurophysiological research that has provided evidence for the dissociation of the verbal, visual and spatial components of working memory.

Dissociations as discussed here are typically reported to provide evidence for separate mental processes underlying different cognitive tasks. A number of different types of dissociations have been posited (see for example, Dunn & Kirsner, 1988; Shallice, 1988), however, most research reports either single or double dissociations. Dunn and Kirsner (2003, p. 1) explain dissociations in the following way:

> Let *A* and *B* be two tasks and let *a* and *b* be two manipulations, variables or factors. A single dissociation is observed if *a* affects performance on *A* but not on *B.* A double dissociation is observed if, in addition, *b* affects performance on *B* but not on *A.*

2.3 Converging Evidence

Baddeley and Hitch's (1974) model is by no means the only model of working memory to be developed. Indeed a number of researchers have argued that working memory is a unitary rather than a multicomponent system (e.g., Engle, et al., 1992; Jones, et al., 1995; Just & Carpenter, 1992; Macken & Jones, 1995, 2003). Proponents of unitary models often exclude the slave systems from their models and distinguish between working memory and short-term memory. For example, Just and Carpenter's theory of working memory only considers a component similar to the central executive that is involved in language comprehension. They do not include separate verbal and visuo-spatial components. Engle et al. consider working memory as a single, domain-general system that controls attention and is separate from short-term memory. Close inspection of these competing models, however, reveals that they are, in fact, quite similar to Baddeley and Hitch's model. If one considers Engle and colleague's model, for instance, it can be argued that what they refer to as working memory reflects the central executive component of Baddeley and Hitch's model, while what they term short-term memory is reflected in the phonological loop and the visuo-spatial sketchpad. Moreover, behavioural, neuropsychological, and neurophysiological data converge in providing compelling evidence for the multicomponent nature of working memory.

2.3.1 Behavioural evidence

Interference paradigms have provided a crucial source of evidence for dissociable working memory components. Dual task, or selective interference, experiments combine a memory task with a secondary task, both of which are assumed to tap similar cognitive processes. Evidence that similar processes are involved in the tasks is provided if performance on the memory task is significantly impaired when the two tasks are combined (Baddeley, 1990). A number of studies have adopted this approach to provide evidence for a single dissociation of visual and spatial working memory processes. According to Shallice (1988, p. 34), "a dissociation occurs when a patient performs poorly on one task … and at a normal level or at least at a very much better level on another task." In selective interference studies the same principle applies. The researcher looks to see if the interference affects performance on one type of task more than it does on another. For example, Quinn (1994) found that performance on the Brook's matrix task, a task considered to tap spatial working memory, was disrupted by concurrent arm movements. Conversely, McConnell and Quinn (2000) used selective interference to show that performance on a visual memory task was disrupted by concurrent visual noise.

Della Sala, Gray, Baddeley, Allamano, & Wilson (1999) combined a Corsi block task and a visual pattern memory task with spatial and visual secondary tasks. The spatial secondary task involved tapping pegs, while the visual secondary task involved viewing irrelevant pictures. Corsi block performance was significantly disrupted by spatial tapping but not by irrelevant pictures. In contrast, pattern memory was impaired by irrelevant pictures but not by spatial tapping. Similarly, Tresch, Sinnamon, and Seamon (1993) found a movement discrimination task interfered with a task that required remembering the location of a dot, while a colour discrimination task disrupted performance on an object memory task. These results provide evidence of a double rather than a single dissociation of spatial and visual working memory. In other words, performance on one memory task is impaired by one type of interference but not another, while the opposite is true of the second memory task.

Experimental double dissociations have also been used to provide evidence for a verbal system separate from both the spatial and visual systems. For instance, Logie, Zucco, and Baddeley (1990) paired visual and verbal memory tasks with visual and verbal suppression tasks. Visual suppression involved visual imagery while verbal suppression involved mental arithmetic. Visual memory performance was significantly impaired by concurrent visual imagery but not by concurrent mental arithmetic. Performance on the verbal task, however, was impaired by concurrent arithmetic but not by concurrent visual imagery. A similar approach was adopted by Farmer, Berman, and Fletcher (1986) using verbal and spatial tasks. Articulatory suppression impaired performance on the verbal reasoning task but had little effect on the spatial reasoning task. Spatial tapping, on the other hand, disrupted performance on the spatial reasoning task but not the verbal reasoning task. The results of these studies suggest that working memory comprises dissociable verbal, visual and spatial components. But because other researchers provide evidence that articulatory suppression can impair performance on visual and spatial tasks, this source of evidence, on its own, is not totally convincing (see for example, Jones et al., 1995; Miles et al., 1996; Simons, 1996). Further evidence for dissociable systems has been provided by developmental fractionation experiments.

Developmental fractionation is based on the premise that different cognitive functions develop at different rates. Differential rates of performance with age on tasks that tap the different types of working memory suggest that the tasks are drawing on different cognitive processes. Logie and Pearson (1997) examined the developmental path of the Corsi block task, a task that is assumed to rely on spatial working memory, and a matrix pattern task, a task assumed to rely on visual working memory. Visual memory was found to develop at a significantly faster rate than spatial memory, suggesting two distinct components. However, Pickering et al. (2001) argued that the distinction was not a visual/spatial one but rather a static/dynamic one.

According to Pickering et al. (2001), the tasks used by Logie and Pearson differed, not only in relation to content, but also in relation to the format in which the tasks were presented. The Corsi block task involves movement and therefore presentation is dynamic. The matrix pattern task, on the other hand, is considered a static task because the stimuli are presented as non-moving patterns. Pickering and colleagues used static and dynamic versions of the matrix pattern task to test this hypothesis. The static version of the task was the same as the matrix pattern task used by Logie and Pearson (1997). For the dynamic version the squares of the patterns were presented sequentially rather than simultaneously. Developmental differences were found on both tasks leading the researchers to conclude that the results provided evidence of a dissociation between static and dynamic processes, rather than reflecting a developmental dissociation between visual and spatial working memory. However, one could argue that the dynamic version of the task used by Pickering and colleagues was actually a variation on the Corsi block task and therefore was a spatial memory task. The static version, on the other hand, was the same as typical matrix patterns tasks which assess visual working memory. The distinction would therefore remain a visual/spatial one, a distinction that has received support from research on patients with damage to specific regions of the brain.

2.3.2 Neuropsychological evidence

Farah, Hammond, Levine, and Calvanio (1988) argued that spatial and visual tasks draw on distinct cognitive resources. They compared the performance of a brain-damaged patient to the performance of normal subjects on tasks that were assumed to assess either visual (colour, size, and shape) or spatial (object location and transformation) imagery. The patient, L.

H., had damage to both temporal-occipital regions of the brain, as well as to the right temporal and right inferior frontal lobes. L. H. performed poorly on the visual tasks, but his performance on the spatial tasks was either better than, or equal to, that of the normal subjects.

Luzzati, Vecchi, Agazzi, Cesa-Bianchi, & Vergani (1998) studied a 74 year old woman, E, P., who was in the early stages of Alzheimer's type dementia and as a result the anterior portion of her right temporal lobe was atrophied. A number of tasks were used to test E. P.'s ability to recall visual and spatial information including the Corsi block task and memory for the visual characteristic of objects (e.g. vegetables and animals). Performance on the visual task was comparable to that of normal controls. In contrast, performance on the spatial task was severely impaired suggesting that the visual and spatial systems are dissociable systems. Taken together these two studies provide evidence of a double dissociation between visual and spatial working memory.

Temple and Richardson (2006) report the case of patient M. M. who had impaired verbal memory but intact visual memory. Similarly, Williams, Goldstein, Carpenter and Minshew (2005) found a dissociation between verbal and spatial memory, impaired verbal and intact spatial, in autistic children and adults. In contrast, Temple (1992) reported the case of patient Dr S. who had the opposite pattern of impairment, intact verbal memory but impaired visual memory.

Further neuropsychological evidence has been provided by Carlesimo, Perri, Turrizani, Tomaiuolo, and Caltagirone (2001), Della Sala et al., (1999) and Mammarella, Cornoldi, and Donadello (2003). Carlesimo et al. describe a patient, M. V., who developed a spatial working memory deficit after suffering an ischemic stroke resulting in damage to the right fronto-parietal region of the brain. M. V had normal intelligence and his verbal and visual working memory remained intact. Della Sala et al. describe two brain-damaged patients with impaired performance on the Corsi block task but not on a visual task and one patient with the opposite pattern of impairment. Mammarella and colleagues compared a number of children with spina bifida to a group of children without spina bifida on tasks designed to assess either spatial (Corsi blocks) or visual (House Visual Span) working memory. Children with spina bifida performed comparably on the spatial task but performance on the visual task was impaired.

Neuropsychological data, when considered in conjunction with behavioural data, provide strong evidence that verbal, visual and spatial working memories rely on distinct cognitive processes. This evidence is made even more convincing when combined with data from neurophysiological research.

2.3.3 Neurophysiological evidence

Clearest evidence for dissociable components of working memory comes from neuroimaging data utilising positron emission tomography (PET) and functional magnetic resonance imaging (fMRI). These data show that distinct neural circuits underpin verbal, visual and spatial working memories. Verbal working memory is mediated by a left hemisphere, frontal-parietal neural circuit with posterior parietal areas involved in storage and Broca’s area, premotor cortex, and supplementary motor areas involved in rehearsal (Schumacher et al., 1996; Smith & Jonides, 1998; Smith, Jonides, Marshuetz, & Koeppe, 1998). Spatial working memory has been found to be mediated by primarily right hemisphere regions including areas in the posterior parietal, occipital, and frontal cortices (Cabeza & Nyberg, 2000; D'Esposito et al., 1998; Jonides, 1993). For visual working memory the primary areas of activation are in the left hemisphere and include inferior temporal, inferior frontal, and posterior parietal cortices (Smith et al., 1995). It is important to note that although activations in neuroimaging studies are typically stronger in one hemisphere than in the other, bilateral activations are also often found. The purpose of activations in homologous areas of the opposite hemisphere is unclear (Henson, 2001). However, it is also important to stress that there is no evidence of opposite lateralisation. In other words, verbal working memory is always left lateralised and never right, spatial working memory is right lateralised and never left, and visual working memory is left lateralised and never right, at least in young adults.

Recent years have seen a surge of neurophysiological studies of working memory functioning using techniques including PET, fMRI, and event-related potentials (ERP). For example, Ruchkin and colleagues (Ruchkin, Johnson, Grafman, Canoune, & Ritter, 1992; 1996) found that different patterns of scalp topographies underlie performance on verbal, visual and spatial working memory tasks. Differences in ERP topographies are indicative of different areas of brain activity mediating the different memory systems. Smith and Jonides (1999) conducted a review of neuroimaging studies that used PET or fMRI to examine regions of brain activity during working memory tasks. They found that not only did central executive processes and storage processes activate different areas, but verbal, visual and spatial working memories also showed different patterns of activation. Central executive processes activated the dorsolateral prefrontal cortex and the anterior cingulate cortex. Verbal working memory involved activations in the left posterior parietal cortex, Broca's area, the left supplementary motor area, and the premotor area. The latter three areas have been shown to be important for the preparation of speech and are assumed to support a verbal rehearsal system (Smith & Jonides, 1999). The left posterior parietal cortex appears to be important for the storage of verbal material.

Neurophysiological research has also provided evidence supporting the dissociation between visual and spatial working memory. For example, research on repetition effects has shown that these effects are greater for spatial memory than for visual memory, suggesting that maintenance of visual and spatial information relies on different neural circuits (Landau, Schumacher, Garavan, Druzgal, & D'Esposito, 2004; Olesen, Westerberg, & Klingberg, 2004; Sayala, Sala, & Courtney, 2005). Smith and Jonides (1999) also found that visual and spatial working memory involves different neural circuits. These circuits are similar to those found in single-cell recording studies of monkeys (Wilson, Scalaidhe, & Goldman-Rakic, 1993). Visual working memory is mediated mainly by ventral regions in both the posterior and frontal regions of the brain, while spatial working memory is mediated by dorsal regions. However, not all research supports a dorsal-ventral distinction within the frontal lobes. Wager and Smith (2003), for instance, conducted a meta-analysis on a number of PET and fMRI studies of verbal, visual and spatial working memory and found that the dorsal-ventral distinction between visual and spatial working memory in posterior regions of the brain did not continue to the frontal cortex. The distinction in the frontal lobe, according to Wager and Smith, was based on the type of processes needed to perform verbal, visual and spatial working memory tasks. Tasks requiring more than just simple storage activated dorsal frontal regions to a greater extent than storage only tasks. An interesting study by Oliveri et al. (2001) using transcranial magnetic stimulation (TMS) supported Wager and Smith's view. They found that TMS delivered on bilateral temporal regions interfered with visual memory but not spatial memory, whereas TMS on bilateral parietal regions had the opposite effect. Oliveri et al. also found that when TMS was applied on dorsolateral prefrontal cortex both tasks were affected, suggesting that this region was responsible for general working memory processes regardless of material type. However, Leung, Gore, and Goldman-Rakic (2002) provide evidence that the middle frontal gyrus region of the prefrontal cortex is involved in the storage of spatial locations in humans (see also Goldman-Rakic & Leung, 2002).

Despite the debate regarding the basis of the distinction in the frontal lobes, the neurophysiological data discussed above converge with behavioural and neuropsychological research to show that working memory is best thought of as a multicomponent system.

2.4 Conclusion

Working memory has been shown to be important for performance on a number of complex cognitive tasks (Miyake & Shah, 1999). Although a number of working memory models have been proposed, Baddeley and Hitch's (1974) model has been particularly influential within the area of cognitive psychology, generating a vast amount of research. Of particular importance is the multicomponent nature of the model which has been supported by behavioural, neuropsychological, and neurophysiological research. Such research provides convincing evidence that working memory comprises distinct systems for processing and storing verbal, visual and spatial information. Gaining a complete understanding of working memory functioning therefore requires consideration of each of these systems. Studying the separate verbal, visual and spatial memory processes is particularly important in cognitive aging research because each of the different types of memory may be differentially affected by age. The effect of age on verbal, visual and spatial memory will be discussed in Chapter 3.

CHAPTER 3

Working Memory and Aging

3.1 Chapter Introduction

The number of older adults living in Australia is steadily rising. Figures released by the Australian Bureau of Statistics (ABS) in 2002 show that the percentage of the total Australian population over 65 years rose from 4% in 1901 to 13% in 2002. The ABS projects that this figure will rise to between 27% and 30% by 2051. The proportion of Australians over 85 years is also expected to rise from 1.4% in 2002 to between 7% and 11% in 2051 (ABS, 2002), the fastest growing segment of the population. These projections are based on a number of assumptions relating to fertility, mortality, and migration, and are illustrative of age changes rather than being actual forecasts. However, they do indicate that our population is aging, highlighting the need for increased understanding of any changes that may occur as a function of age and how these changes may affect older adults' daily lives. One of the most documented findings in the aging literature is that cognitive functioning declines as a function of increased age.

The present chapter will look at the issue of cognitive aging which has been defined by Salthouse (1991) as the "decrease in performance on various measures of cognitive functioning associated with increasing age" (p.1). It will examine how the speed at which one can process information and working memory functioning are related to changes in cognitive functioning across the adult lifespan. An overview of age-related changes in working memory processes as reported in the literature and a discussion of the issue of differential decline will follow.

3.2 Cognitive Aging

Decline in cognitive functioning can to lead to psychological distress in those who experience it. Yet, it has been suggested that a certain amount of cognitive impairment, in the absence of dementia, is to be expected as we age (Park, O'Connell, & Thompson, 2003). Indeed, age-related differences in cognitive functioning have been well documented. Decrements in performance have been reported on a number of cognitive tests including Verbal Analogies and Following Directions subtests of the Army Alpha (McCrae, Arenberg & Costa, 1987); Digit Symbol, Picture Completion, Picture Arrangement, Object Assembly and Block Design (which are Wechsler Adult Intelligence Scale (WAIS) subtests; Kaufman, Reynolds, & McLean, 1989); Primary Mental Abilities Reasoning and Space tests (Schaie, 1985); Ravens Progressive Matrices Tests (Burke, 1972; 1985); and on complex memory tasks such as free recall (Park et al., 1996). Decrements in performance on some measures have been found to begin in early adulthood and generally continue to decline in a linear fashion across the lifespan (Verhaeghen & Salthouse, 1997).

A generally accepted view of cognitive aging is that age-related differences in cognitive functioning are mediated by one or more basic cognitive mechanisms, or processing resources. Processing resources refer to the capacity an individual has available to process information (Craik & Byrd, 1982; Hartley, 1992). This capacity is presumably in limited supply and decreases with increased age. Although the number and the nature of the mechanisms involved in cognitive aging are a matter of debate, processing speed, working memory, and inhibitory and sensory functioning provide examples of processing resources that have been found to be sensitive to age-related decline (Park, 2000). The present dissertation is interested in the relationship between processing speed, working memory, and age rather than the role of the different processing mechanisms in performance on various cognitive tasks. As a result, inhibitory and sensory functioning measures will not be included in this thesis, however a brief overview of these approaches to cognitive aging will be provided.

According to the inhibition view of cognitive aging, age-related decline on cognitive tasks is the result of a decline in the ability to inhibit irrelevant information (Hasher & Zacks, 1988). Items presented in an earlier trial are thought to interfere with the processing of items presented in later trials. However, it has been suggested that reported inhibition effects may not be due to the inability to inhibit irrelevant information but to decrements in source memory (Hedden & Park, 2002). The sensory functioning view, on the other hand, proposes that basic visual and auditory functioning may be an important mediator of age-related differences on cognitive tasks (Lindenberger & Baltes, 1994). According to Lindenberger and Baltes, sensory functioning affects cognitive functioning because it affects neurological health; therefore it is more fundamental than processing speed. However, Park et al. (2002) found no evidence to suggest that sensory functioning was more fundamental than processing speed in explaining age-related differences in cognitive functioning. Park and colleagues argued that it is possible that Lindenberger and Baltes results reflected the large number of extremely old participants tested by these researchers (aged up to 105 years). The reader is directed to the work of Hasher and colleagues (Hasher, Stoltzfus, Zacks, & Rympa, 1991; Hasher & Zacks, 1988) for a discussion of the role of inhibition and to Lindenberger and Baltes (1994; 1997) for a discussion on sensory function.

An increasing number of cognitive aging researchers believe that a single mechanism may be responsible for age-related differences in cognitive functioning (Salthouse, 1991; 1996a). It is also becoming increasingly clear that the speed at which one can process information mediates a large portion of age-related variance on a number of cognitive tasks regardless of whether the tasks are speeded tasks or not. As a result it is often considered a ‘fundamental’ mediator of the relationship between age and cognition (Bryan & Luszcz, 1996; Hertzog & Bleckley, 2001; Luszcz & Bryan, 1999; Park et al., 1996; Salthouse, 1992).

3.2.1 Speed of information processing

Speed of processing can be defined as the amount of time it takes to perform the cognitive operations involved in a particular task (Slater, 1995). The amount of time it takes to execute the requirements of a task increases as a function of age (Salthouse, 1994a; 1996a; 1996b). Salthouse (1996a) has argued that the relationship between speed and cognition is a function of two different mechanisms – the limited time mechanism and the simultaneity mechanism. The limited time mechanism prevents complex tasks from being completed because processing of early operations is too slow, leaving little time to process later operations. The simultaneity mechanism operates in other tasks and prevents successful task completion because the results of early processing are lost before later operations have been completed.

Evidence for the processing speed view to cognitive aging has come from a number of sources (Hertzog & Bleckley, 2001; Lindenberger, Mayr, & Kliegl, 1993; Luszcz, Bryan, & Kent, 1997; Park et al., 1996; Salthouse, 1993, 1994a, 1995; Salthouse & Babcock, 1991). For example, Salthouse and Babcock (1991) tested 460 participants between the ages of 18 and 87 years on three measures of processing speed; letter comparison, pattern comparison, and the Digit Symbol Substitution test, as well as a number of working memory, storage capacity, and processing efficiency tasks, to assess which processing resource was implicated in age-related variance in working memory functioning. Negative relationships were found between age and the working memory measures. However, statistically controlling for measures of processing speed substantially weakened this relationship, suggesting that age-related variances in working memory functioning were mediated by a reduction in the rate at which individuals could perform the processing requirements of the tasks.

Salthouse (1993) also found that age-related variance on a number of measures of fluid cognition was reduced after the statistical control of processing speed, in this case by approximately 80%. Similarly, Bryan and Luszcz (1996) showed that controlling for speed reduced the age-related variance on free recall by a staggering 91%. Speed of processing can therefore be considered an important contributor to the age-related variance on many cognitive tasks and as such, measures of processing speed should be included in cognitive aging studies. However, it does not paint a complete picture as there is often considerable age-related variance not accounted for by speed (Hultsch, Hertzog, Small, McDonald-Miszczak, & Dixon, 1992; Nettlebeck & Rabbitt, 1992; Rabbitt, 1993).

Many cognitive aging studies have found that although speed mediates a large portion of age-related differences on measures of cognitive functioning, working memory also plays an important role, particularly on complex memory tasks such as free recall (Luszcz & Bryan, 1999; Park et al., 1996; Reuter-Lorenz et al., 2001; Verhaeghen & Salthouse, 1997). Vehaeghen and Salthouse conducted a meta-analysis on 91 studies of cognitive aging. Using structural equation modelling techniques they found that the model that best fit the data was one in which both processing speed and working memory were mediators of the age-related variance on a number of cognitive tasks. The authors argued that "age-related declines in speed and working memory capacity, efficiency, or both appear to be involved in the age-related decline evident in more complex aspects of cognition" (Verhaeghen & Salthouse, 1997, p. 246).

Park et al. (1996) used structural equation modelling to examine which constructs were related to age-related variance on measures of long-term memory. Speed was instrumental in explaining a large portion of the variance on the memory tasks, exerting its influence indirectly through working memory. Age-related variance on tasks that are not considered demanding, for example spatial recall, was totally mediated by speed; working memory was not a contributing factor. However, working memory had a direct path to the more effortful types of long-term memory measures, such as free recall. Free recall is considered a task that places high demands on available resources (Craik & McDowd, 1987). These results show that working memory is an important factor in cognitive aging, particularly when tasks place high demands on available processing resources.

A large proportion of age-related variance in performance on a variety of cognitive tasks is shared between speed and working memory. Therefore, as Verhaeghen and Salthouse (1997) suggested, theories of cognitive aging need to consider the role of both processing speed and working memory in the aging process.

3.3 Working Memory and Age

As was previously mentioned (Chapter 3, Section 3.1), age-related differences in cognitive functioning are assumed to be mediated by differences in one or more processing resources. The capacity an individual has available to process information. Speed of processing is one such resource. Another resource, which is required for performance on cognitive tasks, and which has been found to be sensitive to age-related decline, is working memory (Daily, Lovett, & Reder, 2001; Park, 2000). Age-related declines in working memory have been found to result from an inability to use efficient task strategies (Daigneault & Braun, 1993), differences in the time it takes to process information (Salthouse, 1994b), or because of an inability to inhibit information that is not relevant to a task (Hasher & Zacks 1988; Lustig , May, & Hasher, 2001). However, there is some dispute as to whether an inhibitory function causes age-related impairment in working memory functioning (see Chaytor & Schmitter-Edgecombe, 2004; West, Ergis, Winocur, & Saint-Cyr, 1998).

Working memory comprises at least three different types of memory representations – verbal, visual and spatial (see Chapter 2, Section 2.3). Are each of these different types of memory affected by increased age? Age-related declines in verbal memory have been well documented. Declines have also been reported for spatial memory. However, the effects of age on visual memory are less clear. Research relating to verbal, visual and spatial working memories and age will now be discussed.

3.3.1 Age and verbal memory

Park and colleagues (Park et al., 1996) tested 301 participants aged between 20 to 90 years of age on a number of tasks including three verbal working memory tasks, computation span, reading span, and backward digit span. Performance on all of the working memory tasks declined as a function of increased age. Moreover, the declines were large and generally linear with each decade showing a decrease in performance. Meguro, et al. (2000) also found declines in verbal working memory using a Japanese version of the reading span task and simple verbal span tasks including digit span forward. Similar results have been reported by Babcock and Salthouse (1990) using complex and simple arithmetic tasks. In each of these studies mean length of span for older adults was significantly lower than the mean spans for younger adults. For example, Babcock and Salthouse (1990) found the mean spans for younger adults were 4.61 on the complex arithmetic task and 12.09 on the simple arithmetic task. For older adults mean spans were 2.58 on the complex task and 9.56 on the simple task.

There is general consensus among cognitive aging researchers that performance on verbal short-term memory tasks is not as age-sensitive as performance on verbal working memory tasks (Morris, Gick, & Craik, 1988; Light & Anderson, 1985), as is evident in the results of the Babcock and Salthouse study discussed above. Short-term memory tasks can be defined as tasks that simply require the storage of information and include tasks such as digit span forward and word span. Working memory tasks, on the other hand, require information be stored and manipulated simultaneously, for example, digit span backwards, computation span, reading span, and so on (Engle, Tuholski, Laughlin, & Conway, 1999; Miyake, et al., 2001). Performance on short-term memory tasks primarily depends on the phonological loop or visuo-spatial sketchpad functioning, whereas working memory tasks depend more heavily on the central executive (Babcock & Salthouse, 1990). Usually age decrements on short-term memory tasks are not as severe as those found on working memory tasks, although results from some research indicate that age-related declines on the forward and backward versions of the digit span task occur at the same rate (Grégoire, & Van der Linden, 1997; Hester, Kinsella, & Ong, 2004). These results may suggest, as the authors conclude, that both forward and backward digit span tasks require central executive processes.

The important point to be drawn from the previous discussion is that, in the verbal domain, a clear distinction exists between short-term and working memory tasks (Engle, et al., 1999; Kane, Bleckley, Conway, & Engle, 2001; Miyake et al., 2001). Each of these types of tasks may be differentially affected by age. Hence, verbal working memory tasks may be better predictors of age-related changes than verbal short-term memory tasks. The difference in age-related declines between verbal short-term memory and verbal working memory tasks is consistent with the frontal lobe hypothesis of aging. According to the frontal lobe hypothesis, cognitive functions supported by prefrontal areas of the brain will be more susceptible to age-related decline because these areas are more dramatically affected by the aging process than posterior regions (West, 1996; although see Greenwood, 2000 for an alternative view).

Overall, the results from verbal working memory studies show that performance declines as a function of age. Declines are more evident in tasks that require central executive processes than in tasks that rely solely on the phonological loop. Findings from the spatial and visual domains, however, are not quite so clear.

3.3.2 Age and visuo-spatial memory

Early research into age-related changes in visuo-spatial memory used tasks that involved memory for a variety of items and their locations. For instance, Puglisi, Park, Smith, and Hill (1985) found age-related decrements in tasks that assessed memory for the locations of real-world objects, such as watches and spools of thread arranged on a matrix (Experiment 1) and real-world objects and object words (Experiment 2). Charness (1981) found age-related decline in memory for the location of chess pieces on a chess board and Light and Zelinski (1983) reported similar results using structures and their locations on a map. Rather than testing visual or spatial memory, however, these studies tested memory for combined visual and spatial stimulus features. Task that assess memory for combined features are often referred to as feature binding tasks and research has shown that older adults are typically impaired on feature binding tasks (see for example, Cowan, Naveh-Benjamin, Kilb, & Saults, 2006 and Mitchell, Johnson, Raye, & D'Esposito, 2000). Because these tasks include both visual and spatial components it is not possible to determine from these studies whether visual or spatial memory is impaired, or whether both are impaired. There is clear evidence (as discussed in Chapter 2, Section 2.3.3) that visual and spatial memories are subserved by distinct neural circuits and should therefore be examined as separate memory processes.

More recent research has assessed age-related changes in visuo-spatial working using tasks that tap visual memory or spatial memory separately rather than combinations of these features. For example, Jenkins, Myerson, Joerding, and Hale (Experiment 2, 2000) found age-related differences on a location span task which involved the sequential presentation of a series of crosses in various locations on a 4×4 matrix. Older adults had smaller memory spans (*M* = 4.62) than younger adults (*M* = 7.58). Park et al. (2002) used the forward and backward versions of the Corsi Blocks task as well a line span task and a letter rotation task to show that visuo-spatial working memory declined at the same rate as verbal working memory did. Each of these tasks can be considered purely spatial tasks so one could suggest that the declines were in spatial memory and not in visual memory. Hester et al. (2004) conducted a secondary analysis on data from the standardisation sample of the third edition of the Wechsler Memory Scale and also found age-related differences on the forward and backward versions of the spatial span task. Taken together, the results from these studies lead to the conclusion that spatial memory declines with age.

In contrast to the above results, however, Olson, et al. (2004) found no impairment in older adults' spatial memory as compared to young adults'. Olson and colleagues used a change-detection task to assess spatial memory. The task involved presentation of either three or six green squares during the study phase and then either the same display or a display where the location of one of the squares had been changed. The task was to determine whether a square that was enclosed by a box was in the same location as it was in the original display or in a different location. A potential problem with this task, however, is that all the items were presented simultaneously. As a result, it would have been possible for participants to encode the display as a gestalt figure rather than encoding the single locations. If this were the case, then performance on the task could have reflected visual memory processes rather than spatial memory processes. It may well be, as Sekuler, Kahana, McLaughlin, Golomb, and Wingfield (2005) argue, that visual memory is not affected by age.

Sekuler et al. (2005) examined age-related differences between young and older adults on a visual recognition task. Using sinusoidal gratings as stimuli, they found no decrement in performance as a result of increased age, suggesting that visual memory was not affected by age. While Sekuler et al. argue that there is no change in visual memory across the lifespan; other research suggests that there is. For example, Leonards, Ibanez, and Giannakopoulos (2002) found declines in visual memory performance for faces and doors as a function of increased age. Smith and Park (1990) conducted a review of the literature and reported age differences in memory for a number of visual stimuli including faces and abstract drawings. Results from research by Shaw, Helmes, and Mitchell (2006) failed to resolve the issue of whether visual memory changes with age or not. They found a weak negative, but nonsignificant correlation between age and visual memory on an irregular polygons task. On the basis of their results, they concluded that even though the correlation between age and visual memory was weak, there was still evidence of a decline in visual memory. It is difficult however to draw any strong conclusions from this study because of the restricted age range (18 to 57 years) of the participants. Cognitive aging researchers typically do not consider participants under the age of 60 years to be old adults. Hence, one cannot determine from these results whether visual memory continues to decline beyond 60 years of age or whether it remains relatively unaffected.

There is very little research examining the effects of age on visual memory and it is difficult to determine from the research that has been conducted whether there is any change in visual memory across the adult lifespan or not. Furthermore, methodological problems in much of the research in the visuo-spatial domain mean the issue is far from resolved. For example, visual research typically uses recognition tasks to assess visual memory whereas verbal and spatial research typically involves recall tasks. There is some evidence that recall is more age-sensitive than recognition (Craik & McDowd, 1987; Perfect, 1997). However, the difference between recall and recognition tasks is usually examined using verbal stimuli; therefore it is unclear whether visual and spatial recognition tasks are as age sensitive as visual and spatial recall tasks. The visuo-spatial sketchpad is thought to be more closely linked to the central executive than the phonological loop (Baddeley, Cocchini, Della Sala, Logie, & Spinnler, 1999; Miyake, et al., 2001); if this is the case, one would therefore assume that recognition tasks in this domain would be equally as sensitive as recall tasks. Further, neurophysiological research typically uses recognition tasks to assess all types of memory, and results from this research have noted age differences (Reuter-Lorenz et al., 2000). Because of the difficulty in developing recall tasks for the visual domain, it would be beneficial to compare age-related differences on verbal, visual and spatial recognition tasks. If recognition tasks can be shown to be effective in discriminating age-related changes, then these tasks could be used in neurophysiological as well as behavioural research. Using the same types of tasks in both neurophysiological and behavioural cognitive aging research would help increase the generalisability of the results between the different paradigms.

Another important methodological issue is that previous research on age-related changes in visual and spatial memory has not controlled for the possibility that participants may have used verbal encoding strategies to remember the items. Humans have a natural tendency to attach verbal labels to visuo-spatial stimuli (Bahrick & Boucher, 1968). If participants are using, or even attempting to use, verbal labels then any changes that have been found in previous research may reflect changes in verbal memory rather than changes in visual or spatial memory. Sekuler et al. (2005) went some way to resolving this issue by using sinusoidal gratings which have been shown to be difficult to verbally label (Kahana & Sekuler, 2002). Other stimuli that have been used to assess visual memory, for example, abstract polygons and matrix patterns, have also been shown to be difficult to label verbally (Vanderplas & Garvin, 1959; Wilson, Wiedmann, Hadley, & Brooks 1989), however, recent research shows that people still try to attach labels to these stimuli (Postle, D'Esposito, & Corkin, 2005). If participants are still trying to attach verbal labels to items that are difficult to verbally label, performance will not reflect the use of visual or spatial processes alone. As mentioned in Chapter Two (Section 2.2.3) one approach that can be adopted to minimise verbal encoding strategies in visual and spatial tasks is to include an articulatory suppression task during the encoding stage of the task. When examining differences in visual and spatial memory it is important that researchers rule out the possibility that the results may actually reflect only verbal memory processes. This is particularly important when looking at age-related differences in working memory because verbal, visual and spatial memories may be differentially affected by age.

3.4 Differential Rate of Decline?

It is generally accepted that working memory processes show different developmental paths (see for example, Hitch, 2002; Logie & Pearson, 1997;

Jenkins, Myerson, Hale, & Fry, 1999). What is not clear however is whether changes that occur in these processes across the adult lifespan show similar differential paths. In other words, do verbal, visual and spatial working memories decline at different rates? There is some evidence to suggest that this may be the case, however, there is also evidence to suggest the contrary.

An early study by Tubi and Calev (1989), which compared older and younger adults' ability to recall either words or designs to middle-aged adults' performance on the same tasks, found that older adults performed more poorly on both tasks than younger and middle age adults. Younger adults performed better than the middle-aged group. Interestingly, older adults' performance on the visuo-spatial task was poorer than their performance on the verbal task while younger adults performed better on the visuo-spatial task than on the verbal task. Hence, adults of all ages showed differential ability in processing verbal and visuo-spatial information. However, increased age had a greater affect on older adults' ability to process visuo-spatial information than verbal information, suggesting that the processing of verbal and visuo-spatial information was differentially affected by age.

Further evidence for the differential affects of age in the processing of verbal, visual and spatial information has been provided by a number of researchers (Jenkins, et al., 2000; Myerson, Hale, Rhee, & Jenkins, 1999; Schaie & Willis, 1993). Schaie and Willis (1993) showed that the rate of age-related differences across verbal and visuo-spatial psychometric tasks, including processing speed tasks, was not the same. The rate of age-related change was greater for visuo-spatial information than for verbal information. Jenkins et al. (2000) replicated these results for the processing speed tasks and then extended them to include verbal and visuo-spatial working memory tasks and tasks that assessed the acquisition of novel verbal and visuo-spatial information. As a result of their findings, the authors concluded that the processing of verbal information is not as sensitive to the effects of increased age as the processing of visuo-spatial information. Myerson et al. (1999) also provided evidence that visuo-spatial memory is more age-sensitive than verbal memory by showing that older adults had lower location spans than digit spans.

Jenkins et al. (2000) used a letter span task and a location span task with and without the inclusion of verbal and visuo-spatial secondary tasks to examine verbal and visuo-spatial working memories. As discussed earlier, the location span task involved the sequential presentation of a series of crosses in various locations on a 4×4 matrix. Sequential presentation of the items overcomes the problems of research by Olson et al. (2004) discussed above, which used simultaneous presentation of the items, in that the items could not have been encoded as a gestalt figure. However, the inclusion of the gridlines of the matrix adds the possibility for participants to verbally encode the locations by making reference to the cells of the matrix. For example, top left, middle, bottom right, and so on. While this possibility would have been minimised in the condition that included the verbal secondary task, the results of the other two conditions, the location span task on its own and the location span task with visuo-spatial secondary task, could have been confounded by verbal processing. It would be beneficial to completely rule out the possibility of verbal recoding on spatial tasks by using non-visible matrices during encoding. Further, the task used by Jenkins and colleagues to assess visuo-spatial working memory was in fact a spatial task. Therefore their results suggest that verbal and spatial working memories may be differentially affected by age but say nothing about visual working memory.

Hester, et al. (2004) also reported differential rates of change between verbal and spatial memory using forward and backward spatial span tasks and forward and backward digit span tasks. Older adults' spans were lower on all the tasks; however, there were greater age differences on both versions of the spatial task than on the verbal task. The results suggest that spatial memory declines at a greater rate than verbal memory does. Hester and colleagues argued that we are less practiced at processing visuo-spatial information than we are verbal information. As a result, processing visuo-spatial information requires greater central executive input than processing verbal information does. Tasks that require central executive functioning are particularly sensitive to the affects of increased age; hence, visuo-spatial tasks show greater rates of decline. Again, these results relate to changes in spatial memory not visual memory.

Leonards et al. (2002) examined age-related changes in visual and verbal memory in a sample ranging in age from 20 to 69 years. They found that visual memory was more age-sensitive than verbal memory despite the fact that they used socially relevant stimuli (faces) to assess visual memory. Although memory for less socially relevant stimuli (doors) was poorer than for faces, memory for both stimuli showed the same rate of decline. This result is not consistent with the view that visual memory is more age-sensitive than verbal memory because people are less practiced at processing visual information than verbal information. Faces are processed every day of our lives and even though different areas of the brain may underpin the processing of faces as compared to other visual stimuli (McCarthy, Puce, Gore, & Allison, 1997), all these areas of the brain form part of the visual processing system. On the basis of the results from a number of studies reviewed in this section, the visual processing system may be particularly sensitive to the effects of age. However, there exists evidence to suggest that the opposite may be true, that is, verbal memory may be more age-sensitive than visuo-spatial memory.

Janowsky, Carper, & Kaye (1996) compared younger and older adult's performance on tasks that assessed memory for the name of objects and tasks that assessed memory for the location of the same objects. Verbal memory was found to be affected by increased age to a greater extent than spatial memory. A major concern with this study, however, was that the retention interval for both the verbal and spatial tasks was one day. Therefore, the results likely reflect changes in long-term memory processes, not working memory processes. Fastenau, Denburg, and Abeles (1996) also found verbal memory to be more age-sensitive than visuo-spatial memory using a number of verbal and visuo-spatial psychometric tasks (Logical Memory, Cowboy Story, Visual Reproductions, and Extended Complex Figure Test). The authors argued that both verbal and visuo-spatial memory decline as a function of increased age but verbal memory performance requires greater processing resources with age and hence is more sensitive to the effects of age. Other researchers have found no difference in the rate of change between verbal and visuo-spatial memories (Kemps & Newson, 2006; Park et al, 2002; Salthouse, 1995; Smith & Park, 1990).

Salthouse (1995) tested 173 participants between the ages of 18 and 88 years on verbal and spatial memory tasks and found no evidence that spatial memory was affected by age to a greater extent than verbal memory. Instead, Salthouse reported that age differences on both types of memory were consistent across the lifespan. Smith and Park (1990) conducted a review of the literature to determine whether older adults had greater difficulty when performing visuo-spatial tasks than verbal tasks. Examining research that had tested older and younger adults on tasks that assessed memory for a variety of visuo-spatial stimuli, including faces and abstract drawings, they concluded that there was little evidence to support the hypothesis that visuo-spatial information was more age-sensitive than verbal information. Finally, Park et al. (2002) conducted an impressive study examining the relationship between verbal and visuo-spatial short-term memory, working memory, and long-term processes. Using multiple measures for each construct, they found that declines in both visuo-spatial and verbal memory continued in a linear fashion across the adult life-span. While the short-term memory tasks were less sensitive to age than the working memory tasks were, there was no difference in declines between the verbal and the visuo-spatial tasks. As a result, Park et al. concluded that verbal and visuo-spatial memories are equally affected by age. Of the tasks used by Park et al. (2002) to assess visuo-spatial short-term and working memory, forward and backward Corsi blocks, line span, and letter rotation were spatial rather than visual tasks. Therefore their results reflect changes in spatial memory and not in visual memory.

As can be seen by this review of the literature, it is unclear whether domain-specific working memory processes change at the same rate or show a differential rate of change. Moreover, most of the studies compared spatial memory performance to verbal memory performance. The only study that has compared verbal, visual and spatial memory was conducted by Shaw et al. (2006), but as has already been mentioned, this study only tested participants up to the age of 57. As a result, it is far from clear whether visual memory shows the same, or different, rate of change as verbal and spatial memory. Whether verbal, visual, or spatial memories decline at different rates or not is an important theoretical question, because if one or more of these processes are not affected by age then they may provide cognitive aging researchers with a means for developing effective strategies to compensate for those processes that do change. For example, if there is no change in visual memory processes across the adult lifespan, then it may be possible to teach older adults to use visual imagery processes to help remember verbal information.

3.6 Conclusion

There is little doubt that cognitive functioning declines as a function of increased age. There is also general consensus that the speed at which an individual can process information plays a fundamental role in mediating age-related variance on many cognitive tasks. Researchers have also shown that working memory capacity is responsible for age-related performance on many complex cognitive tasks.

Any cognitive mechanism found to be involved in age-related changes in cognitive functioning must itself be sensitive to the effects of age. There is an abundant literature reporting age-related differences in verbal working memory. The results in the visuo-spatial domain however have not been so consistent. Most of the research on age-related changes in visuo-spatial working memory has examined spatial memory not visual memory. A number of researchers have reported declines in spatial memory while others have reported no change at all. Some researchers have also shown that spatial memory declines at the same rate as verbal memory does, while others argue that it is more age-sensitive than verbal memory. Similarly, what little research has been conducted on age-related changes in visual memory has failed to reach a resolution. Again some researchers have found age-related declines while others have found that visual memory remains intact across the lifespan. Also, there is a paucity of research comparing verbal, visual and spatial memory performance across the adult lifespan. As a result of the discrepant results reported in the literature on age-related effects in visuo-spatial memory the following questions are left unanswered: (a) Do visual and spatial memory decline as a function of increased age? (b) If so, do they change at the same rate as verbal memory or are they more or less sensitive to the effects of age? The present thesis has been designed to address these questions.

A number of methodological issues in the visuo-spatial literature have been highlighted in the present chapter. Of particular concern is the possibility of verbal encoding of visual and spatial stimuli. As has been discussed previously, articulatory suppression provides researchers with a means of minimising verbal encoding. The effects of articulatory suppression on verbal, visual and spatial memory performance are examined in the following chapter.

CHAPTER 4

Working Memory and Articulatory Suppression

Study One

4.1 Chapter introduction

4.2 Working Memory and Articulatory Suppression

- *4.2.1 Articulatory suppression and the phonological loop*
- *4.2.2 Articulatory suppression and the visuo-spatial sketchpad*

4.3 Research Question and Hypotheses

4.4 Methods

- *4.4.1 Participants*
- *4.4.2 Materials*
- *4.4.3 Memory tasks*
- *4.4.4 Procedure*

4.5 Results

4.6 Discussion

- *4.6.1 Conclusion*

4.1 Chapter Introduction

Articulatory suppression is a technique that involves continuously saying an irrelevant sequence, for example, “blah, blah, blah” out loud during presentation of the to be remembered items of a memory test. Performance on verbal memory tasks is impaired by articulatory suppression because it prevents the items from being subvocally rehearsed by the articulatory control process of the phonological loop. The effect on visual and spatial memory performance of articulatory suppression is less clear, with some researchers finding no effect and other researchers finding impaired performance.

The present chapter examines the effect of articulatory suppression on verbal, visual and spatial memory performance. The chapter describes Study One which was designed to determine whether each of the different types of memories is affected by articulatory suppression. Section 4.2 reviews previous research and presents inconsistencies in this research that led to the current hypotheses. Section 4.4 provides the details of the methodology of the present study. The results of the study will be presented (Section 4.5) and discussed (Section 4.6) and the chapter will close with the conclusions drawn from the results of the study.

4.2 Working Memory and Articulatory Suppression

4.2.1 Articulatory suppression and the phonological loop

Articulatory suppression has been used in previous research to provide evidence for the existence of the two components of the phonological loop of Baddeley and Hitch’s (1974) working memory model. As was discussed in Chapter 2, the phonological loop comprises two components, a phonological store and an articulatory control process. The articulatory control process uses a process of articulation to maintain items in the phonological store. Verbal suppression interferes with this articulatory process (Baddeley, 1990) and subsequently impairs performance on verbal memory tasks (Baddeley, Lewis, & Vallar, 1984; Baddeley, Thomson, & Buchanan, 1975; Cocchini, Logie, Della Sala, McPherson, & Baddeley, 2002; Gregg, Freedman, & Smith, 1989; Pickering, Gathercole, Hall, & Lloyd, 2001; Saito, 1997). Decrements occur because participants are prevented from subvocally rehearsing items held in the store. Hence, the word length effect, in which recall is dependent on the length of the words, is removed by articulatory suppression because the effect relies on the process of subvocal rehearsal (Baddeley, et al., 1984). Suppression also prevents visually presented verbal material from gaining access to the phonological store because it cannot be recoded into its phonological form. As a result, articulatory suppression removes the phonological similarity effect; recall of phonologically similar words is impaired as compared to phonologically dissimilar words, but only when the items are presented visually (Murray, 1968; Salamé & Baddeley, 1982).

Jones et al., (1995) distinguished between steady- and changing-state suppression. Steady-state suppression simply means continuously saying a single syllable or word, as described above. Changing-state suppression, on the other hand, involves repeating a sequence of syllables or words. For example, saying “one, two, three, four, and five” repeatedly. The argument is that changing-state suppression will impair performance on subsequent recall tasks to a greater degree than steady state-suppression will (Jones et al., 1995; Macken & Jones, 1995). The amount of resources we have available to allocate to a particular task is limited even though, as multiple resource theory suggests, separate pools of resource may exist that can be drawn upon by different processes (Wickens, 1992). Performance on one task will interfere with performance on another task if the demands of the first task exceed the capacity that is available to be allocated to that task. It could be expected then, that changing-state suppression would have a much more profound effect than steady-state suppression on recall, because it is much more demanding of attentional resources. However, steady-state suppression also impacts to impair performance on verbal memory tasks but it does not require attentional resources in the same manner as changing-state suppression does.

4.2.2 Articulatory suppression and the visuo-spatial sketchpad

The second slave system of Baddeley and Hitch’s (1974) model, the visuo-spatial sketchpad, was originally assumed to be a unitary system responsible for visuo-spatial information. Recent research, however, has shown that it contains two components, one responsible for visual information and the other responsible for spatial information (Della Sala, et al., 1999; Hecker & Mapperson, 1997; Logie & Marchetti, 1991; Logie & Pearson, 1997; Quinn & McConnell, 1996; Tresch, et al., 1993). Studying the different aspects of visual and spatial memory performance is made difficult because human beings have a tendency to attach verbal labels to non-verbal material (Bahrick & Boucher, 1968; Postle, et al., 2005; Simons, 1996). Visuo-spatial material has direct access to the visuo-spatial sketchpad but the articulatory control component of the phonological loop enables names applied to the material to gain access to the phonological store. Thus, it is possible that recall of visual and/or spatial information requires both visuo-spatial and verbal processes. Articulatory suppression can be, and has been, used in visual and spatial working memory studies as a means of preventing participants from verbally recoding the stimuli, thereby providing a more pure measure of these types of memory (Broadbent & Broadbent, 1981; Frick, 1988). While there is general consensus in the literature that articulatory suppression impairs performance on verbal working memory tasks, findings in the visuo-spatial domain are less consistent.

The phonological loop and the visuo-spatial sketchpad are considered functionally separate systems (Baddeley, 1990). Visual and spatial working memory tasks rely on different processes than do verbal working memory tasks. Therefore, visual and spatial memories should not be affected by the inclusion of a concurrent verbal task unless verbal processes are being used to remember the stimuli. Indeed a number of studies have found that visual and spatial memory performance is not affected by articulatory suppression (e.g., Cocchini et al., 2002; Kessels & Postma, 2002; Pickering et al., 2001; Vandierendonck et al., 2004; Vogel et al., 2001). For example, Pickering and colleagues reported no decrement in performance in children's memory for matrix patterns under articulatory suppression conditions. Articulation was suppressed by having the children say the word "table" repeatedly during the encoding stage of the task, thereby preventing them from verbally recoding the stimuli. It is possible that Pickering et al's results could be interpreted as reflecting the stage of development of the children in this sample. Children below the age of seven use visual codes to remember visual stimuli whereas children over the age of seven tend to use verbal codes (Hitch, 2002; Miles et al., 1996). Although Cocchini et al. (2002) also reported a lack of effect of articulatory suppression using a concurrent verbal load (a sequence of digits) during retention of a series of matrix patterns. Articulation during retention would serve to prevent participants from subvocally rehearsing the items; however, the items would need to have been verbally encoded if they were to be verbally rehearsed. Articulation during encoding should help minimise the chance that the items are being verbally encoded in the first place, thereby reducing verbal processing contributions to visual memory tasks.

Kessels and Postma (2002) tested memory for spatial locations, objects-to-position assignment, and a combined condition. Memory for spatial locations was not affected by the inclusion of an articulatory suppression task performed during encoding or during maintenance. However, suppression during encoding impaired performance for both the other conditions. Vandierendonck et al. (2004) used articulatory suppression to determine whether performance on both the forward and backward versions of the Corsi blocks would be affected. Suppression involved continuously saying the word “the” during the encoding stage of each task. Performance on forward Corsi blocks was not affected by articulatory suppression. The backward version of the task was impaired, but only for longer sequences. Although Vandierendonck et al. (2004) failed to replicate this finding in a later study; other researchers have shown impairments in visual and spatial memory performance with the inclusion of articulatory suppression.

For example, Steward (2002) found decrements in visual memory for irregular polygons with the inclusion of articulatory suppression during encoding but not during retention. Similarly, Miles, et al. (1996) showed that children's performance on a visual patterns task was significantly impaired under articulatory suppression conditions. Simons (1996) reported that visual memory performance was impaired by the inclusion of a shadowing task designed to block verbal labelling, but spatial memory was not. Jones et al. (1995) found that articulatory suppression impaired performance on a spatial memory task – recall of the location of a sequence of dots. These findings suggest that although visual and spatial stimuli may be difficult to name, participants still apparently attempt to attach verbal labels to the items and as a result, performance is impaired during articulatory suppression conditions. If people do have a natural tendency to label visual and spatial stimuli, as argued by Bahrick and Boucher (1968), then one would expect articulatory suppression to impair performance on these tasks, regardless of whether processing of these stimuli rely on different processes than verbal memory or not. One would also expect impaired performance regardless of whether the stimuli are difficult to label or not.

4.3 Research Question and Hypothesis

The above results are inconsistent with those of Pickering et al. (2001) who, as was previously mentioned, found no impairment in performance on a visual memory task using matrix patterns under suppression conditions. Matrix patterns, like irregular polygons, form abstract shapes and are thought to be difficult to name (Wilson, et al., 1989). Inconsistencies in the previous research show that there is no clear evidence of the effect of articulatory suppression on visual and spatial memory. If we are to fully understand the visuo-spatial memory system it is important that contributions from the verbal system are minimised. Articulatory suppression has provided a means for doing this. But, what effect *does* articulatory suppression have on visual and spatial memory performance?

The purpose of the present study was to examine the effect of articulatory suppression on verbal, visual and spatial memory performance across varying memory set sizes. It was hypothesised that articulatory suppression would prevent subvocal rehearsal of the verbal items and therefore performance would be impaired on the verbal memory task. It was also hypothesised that suppression would impair performance on the visual and spatial tasks because it would prevent participants from verbally recoding these stimuli.

4.4 Methods

4.4.1 Participants

The present study comprised 50 participants, 12 men and 38 women, aged between 18 and 53 years (*M* = 24.38; *SD* = 8.62). All participants were first and second year psychology undergraduates from James Cook University, Townsville, Queensland, Australia who received course credit for their participation.

4.4.2 Materials

An 800M Hz Novis Pentium III computer was used to present all three tasks and task instructions. Stimulus presentation for each task was controlled by custom made programs. Participant responses were recorded by the computer.

4.4.3 Memory tasks

All tasks were recognition tasks and all tasks comprised ten trials of three memory set sizes – three, four and six. Capacity of the visuo-spatial sketchpad is thought to be approximately four items (Alvarez & Cavanagh, 2004; Luck & Vogel, 1997; Song & Jiang, 2006; Vogel & Machizawa, 2004). Two of the set sizes used here were, therefore, at or below capacity for these items while one was above. The use of differing set sizes enabled an examination of the effect of articulatory suppression on performance at each of the levels and thereby allowed us to examine whether task difficulty (increased memory load) influenced the affects of articulatory suppression.

Verbal memory was assessed using a modified version of Salthouse and Babcock's (1991) computation span task. The task involved presenting a sequence of simple arithmetic problems comprising single digits (e.g., 2 + 1 – 4 =), one problem at a time on the centre of the screen. Participants' task was to solve the problems and remember the answers for later recognition. Digits and operations were randomly chosen.

Visual memory was assessed using a task based on the Visual Patterns Test (VPT) developed by Della Sala and colleagues (Della Sala, et al., 1999). Matrix patterns were generated by filling random combinations of cells of a white 3×3 matrix. Grid lines of the patterns were then removed leaving a pool of black squared-shaped patterns (see Figure 4.1 for examples). The patterns were presented one at a time on the centre of the computer screen. Matrix patterns were chosen because they have been found to be difficult to verbally label (Wilson, et al., 1989).

Spatial memory was assessed using a dot memory task. Twenty-millimetre white dots appeared one at a time in random locations on a non-visible 7 × 7 matrix. Dots provide ideal stimuli to measure spatial memory because they are difficult to label verbally. Also, when presented one at a time, rather than simultaneously, visual processing can be minimised because sequential presentation prevents the items being encoded as a gestalt figure (Vogel et al., 2001).

4.4.4 Procedure

The current study adopted a within subjects design, all participants completed all tasks in both the suppression and no suppression conditions. Ethics approval was sought and obtained from the James Cook University Ethics Committee before testing began. Participants were tested individually in a sound-proofed room. Identification numbers were randomly assigned and informed consent was obtained before testing began. All tasks began with five practice trials and task instructions were given before testing began. Task instructions were also presented on the computer screen at the start of each task. All memory set stimuli and distracters were randomly chosen. Order of presentation of the tasks, conditions, and set sizes was counterbalanced across participants.

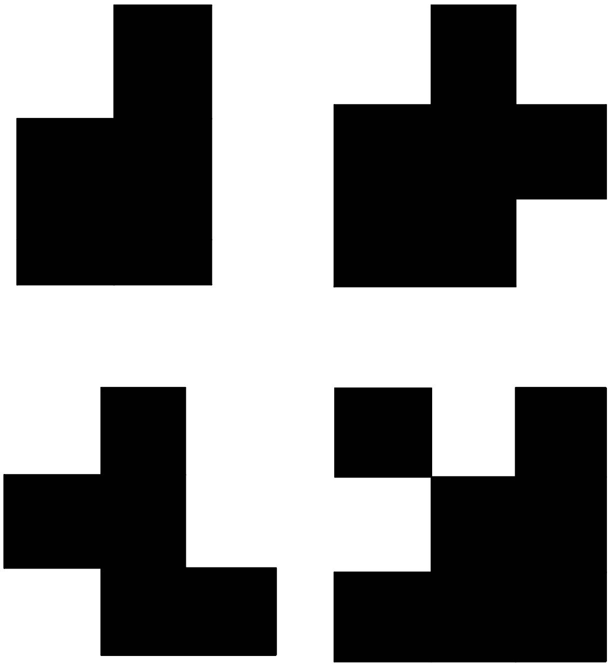

Figure 4.1 Example of some of the patterns used in the matrix patterns task.

Stimuli were presented one item at a time at a rate of two seconds per item (see Postle et al., 2005) with an interstimulus delay of one second and a one second delay between presentation of the last item in the memory set and the recognition items. For each participant there were ten trials of each set size, giving thirty trials for each task in each condition. Once all items of each memory set had been presented, the memory set items plus a number of distracters appeared on the screen. The number of distracters was chosen to limit the chance of guessing a correct response to one in four (25%). Participants were required to use the computer mouse to click on the memory set items in any order. There was no time limit on participant responses. Participants were also able to take a break between tasks and between conditions. A message presented on the computer screen told participants when they had completed each task.

For the suppression condition participants were asked to continually say “blah” out loud while the memory set items were being presented. This type of suppression is considered to be steady-state suppression as discussed in Section 4.2.1 above. Steady-state suppression was used rather than changing-state suppression, because it draws on general rather than attentional resources. Adherence to the suppression was monitored by the experimenter from an adjoining room.

4.5 Results

The dependent measure for each task was the number of items correctly recognised across set sizes, giving a possible total score of 130 for each task. Scores for each task were converted into percentages before analysis. Means and standard deviations were calculated on percentages for each task and each set size in both the suppression and no suppression conditions and are presented in Table 4.1. Percentage correct for the verbal task with suppression ranged from a low of 20.00 to a high of 84.62, the verbal task without suppression from 26.15 to 84.62, visual task with suppression 29.23 to 86.92, visual without suppression from 25.38 to 90.00, spatial task with suppression from 25.38 to 94.62 , and the spatial task without suppression from 59.23 to 98.46. No participant performed at floor or ceiling levels in any of the tasks.

Table 4.1

Mean Percentages Correct and Standard Deviations for Performances on Verbal, Visual and Spatial Memory Tasks Set Sizes Three, Four, and Six during Suppression and No Suppression Conditions

	Verbal	Visual	Spatial
Suppression			
3	54.07 (15.29)	68.53 (17.21)	87.87 (12.08)
4	45.65 (14.24)	60.95 (16.11)	78.85 (16.11)
6	39.07 (11.48)	51.03 (15.30)	60.48 (15.47)
No Suppression			
3	68.67 (17.56)	81.00 (13.76)	92.13 (7.67)
4	59.30 (16.18)	70.55 (16.55)	84.60 (8.95)
6	49.63 (13.12)	60.80 (14.64)	67.07 (12.26)

Note: Standard deviations are shown in brackets.

Data were analysed using a 2 (condition: suppression versus no suppression) by 3 (task: verbal, visual and spatial) by 3 (set size: three, four and six) repeated measures ANOVA with an alpha level of .05. The assumptions of random selection, and normality were examined and no violations were found. Mauchly’s test of sphericity was not significant for the main effect of task, the condition by task interaction, the condition by set size interaction, or the condition by task by set size interaction; therefore the assumption of homogeneity for these factors was not violated. However, Mauchly's test was significant for the main effect of set size and for the task by set size interaction. As a result, the *F*-ratio for these factors was calculated using Huynh-Feldt Epsilon adjusted degrees of freedom. Results of the ANOVA showed a significant main effect for condition, F (1, 49) = 136.71, MSE = 152.49, $p < .001$; $\eta^2 = .74$. There was also a significant main effect for task, F (2, 98) = 129.71, MSE = 380.78, $p <.001$; $\eta^2 = .73$, and set size, F (2, 98) = 363.77, MSE = 105.07, $p < .001$; $\eta^2 = .88$. The interaction between condition and task was significant, F (2, 98) = 6.48, MSE = 158.27, $p <.002$; $\eta^2 = .12$ (see Figure 4.2). There was also a significant task by set size interaction, F (4, 196) = 11.34, MSE = 86.83, $p <.001$; $\eta^2 = .19$. The interactions between condition and set size (F (2, 98) = .70, MSE = 75.18) and between condition, task and set size (F (4, 196) = 1.88, MSE = 52.81) were not significant.

Bonferroni corrected alpha levels were used to control for familywise error for tests of simple effects of the condition by task interaction. Participants recognised fewer items in the suppression than in the no suppression condition in the verbal (t (49) = -7.94, $p < .001$), visual (t (49) = -6.71, $p < .001$) and spatial tasks (t (49) = -4.02, $p < .001$). As can be seen in Figure 4.2, the difference between suppression and no suppression conditions was less in the spatial domain than in the verbal and visual domains.

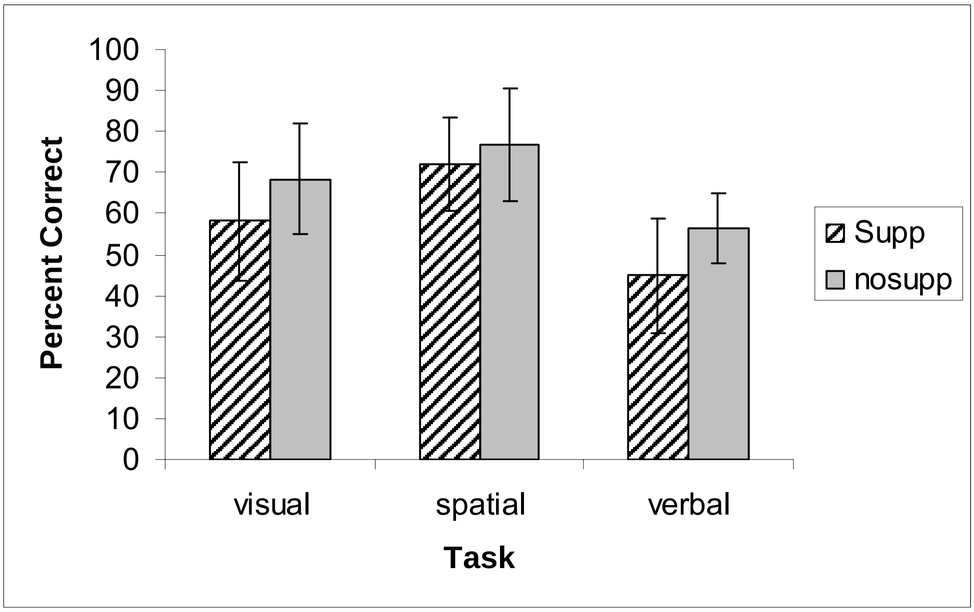

Figure 4.2. Comparison of suppression and no suppression conditions for verbal, visual and spatial memory performance.

Paired samples *t*-tests, with Bonferroni corrected alpha levels, were also conducted to examine the task by set size interaction. For verbal working memory with suppression, there was a significant difference between performance levels on set size three and set size four (*t*(49) = 4.28 = *p* < .0005) and between set size four and set size six (*t*(49) = 4.10, *p* < .0005). For visual memory with suppression, there were significant differences between set sizes three and four (*t*(49) = 3.82, *p* < .0005) and set sizes four and six (*t*(49) = 6.64, *p* < .005). The difference between performance levels on set sizes three and four for spatial memory was significant (*t*(49) = 4.32, *p* < .0005), as were the differences between set sizes four and six (*t*(49) = 11.19, *p* < *.005*). In the no suppression condition, the difference between set sizes three and four (*t*(49) = 5.20, *p* < .0005) and set sizes four and six (*t*(49)

= 7.31, *p* < .0005) for verbal memory were significant. For visual memory, the differences between set sizes three and four (*t*(49) = 6.57, p < .0005) and between four and six (*t*(49) = 6.93, *p* < .0005) were significant, as were the differences between set sizes three and four (*t*(49) = 7.27, *p* < .0005) and four and six (*t*(49) = 11.24, *p*< .0005) for spatial memory. The decline in performance between set sizes was more pronounced between set sizes four and six for spatial memory in both the suppression and no suppression conditions.

To rule out the possibility that performance on the visual and spatial tasks under articulatory suppression conditions may be the result of dual task effects, data for these tasks was further analysed using paired sample *t*-tests. The results of these analyses showed that performance on the visual task was significantly lower than performance on the spatial task, *t*(49) = -7.21, *p* < 0.0001.

4.6 Discussion

The present study sought to determine what effect articulatory suppression had on verbal, visual and spatial memory performance. The hypothesis that performance on the verbal memory task would be impaired by the inclusion of an articulatory suppression task was supported by the results of the present study. This result is not surprising because suppression prevents people from subvocally rehearsing the memory set items and is consistent with previous research (e.g., Baddeley, Lewis et al, 1984; Baddeley, Thomson et al., 1975; Cocchini et al., 2002; Gregg et al., 1989; Pickering et al., 2001; Saito, 1997).

Of more importance for present purposes, the hypothesis that visual and spatial memory would be impaired by articulatory suppression was also supported by these results, although decrements in performance in spatial memory were less than in the other types of memory. It would appear that, consistent with previous research (e.g. Postle et al., 2005; Simons, 1996), participants do use verbal labels to remember visual material even though the material may not be conducive to such labelling. It also appears that articulatory suppression helps in preventing this recoding process from taking place. In contrast to Postle et al. and Simons, however, the results of the present study suggest that verbal labelling occurs in spatial memory tasks as well as in visual memory tasks, but not to the same extent.

It is not likely that the present pattern of results was due to the effect of task difficulty because the condition by set size interaction was not significant. Moreover, if task difficulty was a contributing factor, one would have expected to find no effect of suppression in set size three, and possibly four, because these set sizes did not exceed the capacity of the visuo-spatial sketchpad. One would have expected to find a larger effect of suppression for set size six. However, although performance levels declined as set size increased in all tasks, performance was impaired for all set sizes in the suppression condition as compared to the no suppression condition. Hence, while the capacity of the visuo-spatial sketchpad may have affected the number of items a person could remember on a given task, articulatory suppression appears to have played a role in decreasing performance levels between conditions.

The present study defined task difficulty as an increase in the number of items in a memory set, it is equally plausible that task difficulty could be defined as the amount of central executive processing required at each set size. Using a central executive definition, one would expect to find the same pattern of results as described in the previous paragraph. Of more concern, however, is the suggestion that the visuo-spatial sketchpad is more closely linked to the central executive than the phonological loop (Miyake, et al, 2001). If this is the case, then it is possible that performance in the suppression condition was a function of the increased need of central executive processes under dual task conditions. However, it has been shown that the dual task aspect of suppression studies is not a confounding factor because not all types of non-verbal memory are affected by articulatory suppression. For example, Postle et al. (2005) and Simons (1996) found that spatial memory was not affected by the inclusion of an articulatory suppression task but that visual memory for abstract polygons was affected. Furthermore, it is generally agreed that articulatory suppression, steady-state, does not draw on general attentional resources but rather on distinct verbal processes (Baddeley, 1986). Suppression only impaired performance because representation of the abstract polygons used in these studies relied in part upon a verbal code. In the current study spatial memory performance was impaired under articulatory suppression conditions but not to the same extent that visual memory was. A significant difference was found between performances on the two tasks. If these results reflected dual task effect, a similar pattern of impairment would have been expected. Furthermore, Postle and colleagues found that there was no decrement in performance in a visual memory task when a spatial tracking task was used as the secondary task instead of articulatory suppression. If it was the dual-task nature of the suppression condition, one would have expected to find impaired performance on visual memory tasks when a spatial secondary task was used.

According to Baddeley (1990), the phonological loop and the visuo-spatial sketchpad rely on different processes and as a result, visual and spatial memory should not be affected by articulatory suppression. The results of the present study appear to be inconsistent with this view and could be seen to be providing evidence for functional equivalence (Jones et al., 1992) rather than functional distinction of these two components of the working memory model. However, if people attach verbal labels to visual and spatial stimuli, as they have a natural tendency to do (Bahrick & Boucher, 1968), then they are using both the phonological loop and the visuo-spatial sketchpad when completing these tasks. Articulatory suppression impairs performance on visual and spatial tasks because it prevents participants from verbally encoding the stimuli, thereby leaving them to rely solely on the visuo-spatial sketchpad. Decrements in performance could, therefore be seen to be in verbal memory not visual or spatial memory. As a result, performances on these tasks under suppression conditions would reflect more pure measures of visual and spatial memory.

4.6.1 Conclusion

Verbal, visual and spatial memory performances are all negatively affected by articulatory suppression. Verbal memory is affected because suppression prevents participants from subvocally rehearsing the items, or because it prevents visually presented verbal items from being recoded into their phonological form. Visual and spatial memories are affected because suppression prevents the items from being verbally encoded. As a result, participants need to rely solely on the visual and spatial systems in order to remember these items. If we are to be confident that we are assessing visual and spatial memory, not verbal memory, then we need to prevent visual and spatial stimuli from being verbally recoded. Articulatory suppression provides memory researchers with a means to do so and it should be considered by researchers when conducting research in the visuo-spatial domain.

The previous discussion assumes that the tasks used in this study, and those used in previous research, are reliably and validly measuring verbal, visual and spatial memory constructs. Chapter 5 provides the results of an experiment designed to examine the reliability and validity of the tasks used in this study, plus a number of other tasks that are assumed to measure each of the different types of memory.

Chapter 5

Task Reliability and Validity

Experiment Two

5.1 Chapter Introduction

The central executive and the episodic buffer components of Baddeley and Hitch's working memory model are thought to be domain-general systems. That is, they are assumed to process information independent of material type. The phonological loop and the visuo-spatial sketchpad, on the other hand, are considered domain-specific systems. The phonological loop is responsible for verbal information, and the visuo-spatial sketchpad for visual and spatial information (Baddeley, 2001; Logie & Pearson, 1997). The domain-specificity of these two components highlights the distinction between verbal, visual and spatial working memories.

While the distinction between verbal, visual and spatial working memories is a valid one that has been supported by behavioural, neuropsychological and neurophysiological data (see Chapter 2 Section 2.3), each of the different types of memory are hypothetical constructs. Hypothetical constructs cannot be measured directly; instead, researchers use a number of specially designed indicators as measures of the construct (Hair, Anderson, Tatham, & Black, 1998). It is important that the indicators one uses to measure hypothetical constructs are shown to be reliable and valid. For example, memory tasks that are designed to measure verbal, visual and spatial working memories must be reliable and valid indicators of each of these different types of memory. The present chapter addresses the issue of task reliability and validity. The results of a study designed to examine the test-retest reliability and construct validity of a number of tasks that will be used to examine age-related differences in verbal, visual and spatial working memories are presented. The results will be discussed in terms of Baddeley and Hitch's model of working memory.

5.2 Measuring Verbal, Visual and Spatial Working Memory

Verbal, visual and spatial working memories appear to rely on different cognitive processes (Baddeley, 2001), each of which should be considered in studies examining the nature of working memory processes. Because the different types of working memory are hypothetical constructs, a major obstacle to achieving such an aim lies in the development of reliable and valid measures for each type of memory. A number of tasks have been used in previous research to assess verbal, visual and spatial memory. For example, types of tasks that have been used to assess verbal working memory include reading span, computation span, forward and backward digit span, word span, running memory span, and a variety of others. Spatial memory has typically been assessed using the Corsi blocks task or computer variations, such as the dot memory task, which involve memory for spatial location. The Corsi blocks task is also often used to assess visuo-spatial working memory as a single system. Other spatial tasks include arrow span and letter rotation. Common stimuli in the assessment of visual memory include objects that are considered difficult to verbally label, for example, irregular polygons, matrix patterns, Chinese characters, faces, and colours.

Salthouse and Babcock (1991) emphasised the need to use multiple measures of a construct when assessing individual differences. Composite scores, obtained by combining the scores of all the measures, can then be used as a more reliable reflection of a particular construct. Using multiple measures makes intuitive sense if, and only if, the measures are measuring the same thing. One needs to be sure that computation span and reading span are both true indicators of verbal working memory, for instance. Salthouse and Babcock found that these two tasks were highly correlated (.68) suggesting that they do measure something similar. In this case the tasks may have been assessing central executive functioning. Each task was also quite highly correlated with digit span and word span, suggesting that the phonological loop may also be involved. De Rammeleare, Stuyven, and Vandierendonck (2001), however, found that children with normal phonological loop functioning can have poor arithmetic ability and, conversely, children with impaired phonological loop functioning do not necessarily have impaired arithmetic ability. Their results suggest that the phonological loop may not necessarily be involved in computation span tasks. These results highlight the need to ensure tasks used in working memory studies are reliable and valid indicators of the construct. In the studies discussed here, the emphasis has been on verbal working memory, but the same logic can be applied to visual and spatial memory. For example, can one be certain that both matrix patterns and irregular polygons are true indicators of the construct of visual working memory?

A further concern in relation to task reliability and validity is that different studies present the same type of task in different ways. For example, neurophysiological research typically uses recognition tasks that require same/different responses, whereas behavioural research typically uses recall tasks for verbal and spatial memory and recognition tasks for visual memory. Often neurophysiological research will present a number of items (usually up to seven), followed by a delay, and then a probe. Participants are required to decide whether the probe matches one of the items from the memory set or not. Behavioural researchers, on the other hand, tend present a series of items and participants are required to recall the complete series of items either verbally or by writing the list on paper (Reuter-Lorenz & Sylvester, 2005). The different approaches may be using the same stimuli, but they are using different response criteria. These factors combine to complicate the interpretation of results and the comparisons made between studies. For instance, does an age-related difference in verbal memory mean the same thing for reading span task performance as it does for computation span task performance? Do the different tasks measure the same construct or are they measuring something completely different because a different response system is used? Can we justifiably compare the results of a study using one task with the results of a study that uses a different task or a different methodological approach? Construct validity studies are the only way these questions can be answered. Often it is assumed that tasks are consistently and accurately measuring what we presume them to measure.

When designing verbal, visual and spatial memory tasks, consideration must also be given to the amount of central executive involvement in the task. Visual and spatial tasks appear to rely more heavily on central executive processes than verbal memory tasks do (Baddeley, 1996b). As was mentioned in Chapter 3 (Section 3.2.1), research often distinguishes between working memory tasks and short-term memory tasks (Miyake, 2000). Working memory tasks can be defined as tasks that require the simultaneous processing and storage of information, and thus involve the central executive. Reading span and computation span tasks are considered examples of verbal working memory tasks. Short-term memory tasks, on the other hand, only assess the storage aspects of working memory. Digit span and word span are examples of verbal short-term memory tasks. The distinction between the two types of tasks in the verbal domain is quite clear; however, it may not be quite so clear in the visuo-spatial domain (Hester et al., 2004; Miyake, et al., 2001; Oberauer, et al., 2000). Verbal working memory tasks involve significantly more executive functioning than is involved in verbal short-term memory tasks. In the visuo-spatial domain, on the other hand, both types of tasks appear to involve resources from the central executive. Further, contrary to findings from the verbal domain, in which short-term memory tasks apparently do not predict performance on various cognitive tasks as well as working memory tasks do, visuo-spatial short-term memory tasks have been shown to predict performance on spatial ability tests as well as visuo-spatial working memory tasks do (Miyake et al., 2001). This means that both visual and spatial short-term tasks may be equivalent, in terms of central executive involvement, to verbal working memory tasks (although see Lecerf & Roulin, 2006 for an alternative interpretation).

With the above issues in mind, the present study sought to examine the test-retest reliability and the validity of a number of tasks designed to measure verbal, visual and spatial working memories. The tasks, described in detail in the methods section, are modifications of a number of different tasks that have been reported in the literature. Modification of the tasks was underpinned by the need to ensure that the tasks would be able to be used in both behavioural and neurophysiological research. The basic working memory model of Baddeley would predict that three factors would emerge from the data.

5.3 Methods

5.3.1 Participants

One hundred and five first and second year university undergraduates from James Cook University, Townsville, Australia participated in the current study for course credit. There were 70 women and 35 men ranging in age from 18 to 56 years (*M* = 23.96*, SD* = 9.68*).* Seventy-five of these participants (49 women and 26 men) returned for retesting fourteen days after the original testing session. The data from three participants were excluded from analysis because of extremely low scores on most of the tasks, leaving a sample of 102, 68 women and 34 men (age range 18 to 56 years, *M* = 23.96, *SD* = 9.78) at test. Data at retest was analysed on a sample of 73 (48 women and 25 men), aged between 18 and 56 years (*M* = 23.21, *SD* = 9.55).

5.3.2 Materials

All tasks and task instructions were presented on an 800 MHz Novis Pentium III computer. A custom made program controlled stimulus presentation and recording of participant responses for all tasks.

Each type of memory was assessed using three different tasks, each of which comprised six items per memory set with five trials for each task.

The total possible score for each type of task therefore was 30. All tasks were recognition tasks for consistency in task format and to enable the tasks to be used in both behavioural and neurophysiological research. Because a number of the tasks have been considerably modified from existing tasks, they will be described in some detail and examples will be given.

Given that the distinction between working memory and short-term memory tasks has been shown to be greater in the verbal domain than in visual and spatial domains (Miyake et al, 2000), verbal memory was assessed using three working memory tasks while visual and spatial memories were assessed using two short-term memory tasks and one working memory task.

5.3.3 Verbal Memory Tasks

Verbal memory was assessed using an arithmetic task which was based on Salthouse and Babcock's (1991) computation span task, a consonant task based on the running memory span task (Morris & Jones, 1990; Pollack, Johnson & Knaft, 1959), and a variation of the *n*-back task (Smith & Jonides, 1997). Each of these tasks can be considered working memory tasks because they all required the simultaneous processing and storage of information. The arithmetic task involved presenting a sequence of six simple arithmetic problems, comprising single digits (e.g., 2 + 4 – 1 =), one problem at a time on the centre of the computer screen. Participants' task was to solve the problems and to remember the answers for later recognition. The processing and storage requirements of the task were met by requiring participants to remember the answer to each problem while processing the answer to the next.

The second verbal task, the consonant task, was based on a paradigm introduced by Pollack, et al. (1959) and further developed by Morris and Jones (1990). According to Morris and Jones (1990), the running memory span task requires both phonological loop and central executive processes and therefore would be considered a working memory task. The task involved the presentation of lists of consonants of varying lengths (8, 10 or 12 letters), one list at a time, on the centre of the screen. Consonants for each sequence were presented simultaneously. Participants were asked to remember the last one, two or three items depending on list length. That is, for a list of eight consonants participants needed to remember the last item, the last two for a list of ten consonants, and the last three for twelve consonants. Numbers of consonants in each list varied randomly from eight, ten, or twelve consonants within a memory set. Participants were unaware of how many consonants were in each list until the list was presented. For example, for the following memory set:

N K T R S D P **W**

X V L G F S P Y **Q M**

F H L D C B T N Q **W G X**

S G F L K J Y **T**

C V G H J Y T D S **P L J**

R T Y P K J G **C**

participants would need to retain the letters in bold type face for later recognition. Please note that *no* letters were presented in bold face during testing.

The final verbal task was an *n*-back task, in this case a 3-back task. Single syllable, five letter words, matched for familiarity and frequency of use (Thorndike & Lorge, 1963), were presented one word at a time on the centre of the screen. An asterisk followed presentation of the sequence of words. Each trial comprised random combinations of three, four, or five words to prevent participants from knowing which word was the target word until all words had been presented. For example, for the following trial;

child blood month *
dress court light house price *
force night point *
fight heart chair stand *
cross place plant board world *
green thing start watch *

the participant would need to remember the words *child, light, force, heart, plant, thing,* for later recognition.

5.3.4 Visual Memory Tasks

Visual memory was assessed using an irregular polygon task, a matrix patterns task, and an *n*-back task. Irregular polygons and matrix patterns are considered short-term memory tasks whereas the *n*-back task is a working memory task. Target stimuli for the first task were a number of four and six sided irregular polygons designed by Attneave and Arnoult (1956) that have been shown to be difficult to name (Vanderplas & Garvin, 1959). Random polygons, presented one at a time on the centre of the screen, needed to be remembered for later recognition. The second visual task was based on the Visual Patterns Test (VPT) developed by Della Sala and colleagues (Della Sala, et al., 1999). The current task was different from the VPT in that complete patterns were used as stimuli rather than the individual squares of a matrix (Figure 4.1). A further difference was that the grid lines of the matrices were removed to reduce reference to positions in space – top left, bottom right, and so on. The task involved the presentation of 3 × 3 black and white matrix patterns one at a time on the centre of the screen. The final visual task was similar to the verbal *n*-back task except that irregular polygons were used as stimuli rather than words. An articulatory suppression task, that involved repeating the word “blah” out loud during the encoding stage of all visual tasks, was also included to prevent verbal encoding of the stimuli.

5.3.5 Spatial Memory Tasks

A dot memory task, a letter orientation task, and an *n*-back task were chosen to assess spatial memory. Similar to the visual memory tasks, spatial memory was assessed using two short-term memory tasks (dot memory and letter orientation) and a working memory task (the *n*-back task). Dot memory involved the presentation of a sequence of six dots, one at a time, in various locations around a central fixation point on a non-visible 7 × 7 matrix. The non-visible matrix was used to help prevent verbal encoding of the locations. Articulatory suppression, as described above, was also used to reduce verbal encoding during presentation of stimuli in all the spatial tasks. Participants’ task was to remember the location of the dots. Letter orientation was based on the letter rotation tasks developed by Shah and Miyake (1996) and involved the presentation of a number of letters (A, R or T), one at a time, in different orientations on the centre of the screen. For example, the letter “R” may have been presented upside down. The task was to remember the orientation of the letters. Unlike Shah and Miyake’s task that required participants to use mental rotation to determine whether the letters were mirror images or normal as well as remembering the orientation of the letters, the present task only required memory for the orientation of the letters. The task could, therefore, be considered a short-term memory task because it only required storage processes. Finally, the spatial *n*-back task was similar to the verbal and visual versions except the target stimuli were crosses in various locations around a central fixation point rather than words or polygons.

5.3.6 Procedure

Participants were individually tested in a sound proof room in the Cognitive Sciences laboratory. Identification numbers were randomly assigned and informed consent was obtained before testing began. Ethics approval was sought and received from the James Cook University Ethics Committee. All task instructions were presented on the computer screen and were also given verbally to each participant by the experimenter to avoid confusion. Order of presentation of the tasks was counterbalanced for both the test and retest sessions. Participants were retested 14 days after the first testing session.

For each task the to-be-remembered stimuli were presented one item at a time on the centre of the computer screen for two seconds with a one second interstimulus delay and a one second delay before the presentation of the recognition grid. Each trial comprised a memory set of six items with five practice trials for each task, the dependent measure being the number of items correctly recognised across trials. In the recognition phase of the study, participants were presented with the memory set items plus a number of distracters. The task was to click the computer mouse on the items recognised as being part of the memory set. The number of distracters was chosen to keep the possibility of guessing a correct response to less than one in four. Memory set items and distracters were randomly selected. Participants were made aware that adherence to the articulatory suppression condition would be monitored by the experimenter through an intercom system located in an adjoining room.

5.4 Results

Means and standard deviations were calculated for performance levels on all tasks for test and retest data and are reported in Table 5.1. Correlations between the tasks are presented in Table 5.2. Generally, the highest correlations appear to be between tasks designed to measure the same type of memory, however, significant correlations were also found between tasks from the different memory types. Letter orientation in particular correlated significantly with a number of other tasks.

Test-retest reliabilities ranged from a low of 0.51 for letter orientation to a high of 0.89 for computation span and are reported in Table 5.3. All retests were done 14 days after the initial testing session. Although the test-retest reliabilities show that all the tasks were stable over time, Table 5.1 shows that the means at retest were slightly higher than the test means. Therefore, it was decided to perform a number of Bonferroni corrected, paired-sample *t*-tests to determine whether these differences were significant. The results showed that there was no significant difference between test and retest scores at the corrected alpha level of .005 for all but one of the tasks. There was a significant difference between test and retest scores for the dot memory task, t (72) = 2.89, p = .005.

Table 5.1

Means and Standard Deviations for Verbal, Visual and Spatial Memory Tasks at Test and Retest

Task	Test	Retest
Verbal		
Arithmetic	15.89 (3.15)	15.55 (3.21)
Consonants	15.50 (3.06)	15.70 (3.15)
n-back	15.37 (3.40)	15.83 (3.76)
Visual		
Polygons	13.11 (3.62)	13.94 (3.48)
Matrices	14.76 (3.81)	15.00 (3.20)
n-back	8.98 (2.64)	9.53 (2.47)
Spatial		
Dot Memory	14.99 (3.35)	15.73 (3.52)
Letter Orientation	13.87 (3.64)	13.68 (4.09)
n-back	8.92 (2.77)	9.30 (3.31)

Note. Standard deviations are in parentheses.

Table 5.2

Correlations between Verbal, Visual and Spatial Working Memory Tasks

	1	2	3	4	5	6	7	8	9
1. AR	1.00								
2. Cons	.41**	1.00							
3. Ver*n*B	.21*	. 29**	1.00						
4. PG	.19	.20	.04	1.00					
5. MP	.15	.26**	.01	.47**	1.00				
6. Vis*n*B	-.01	.19	.04	.34**	.27**	1.00			
7. DM	.11	.17	.04	.14	.21**	-.00	1.00		
8. LO	.31**	.25*	.07	.50**	.34**	.23*	.27**	1.00	
9. S*n*B	.19	.30**	.17	.24*	.21*	.23*	.43**	.35**	1.00

Note. *N* = 102. Arithmetic (AR); Consonants (Cons); Verbal *n*-Back (Ver*n*B); Polygons (PG); Matrix Patterns (MP); Visual *n*-Back (Vis*n*B); Dot Memory (DM); Letter Orientation (LO); Spatial *n*-Back (S*n*B).

**p* < 0.05, 2-tailed. ***p* < 0.01, 2-tailed.

Table 5.3

Verbal, Visual and Spatial Memory Tasks Test-Retest Reliability Coefficients

Task	Reliability Coefficient
Arithmetic	0.89**
Consonants	0.84**
Verbal *n*-back	0.79**
Polygons	0.79**
Matrices	0.83**
Visual *n*-back	0.69**
Dot Memory	0.81**
Letter Orientation	0.51**
Spatial *n*-back	0.54**

Note. $N = 73$

**$p < 0.01$.

The factor structure of the data was explored using principle components analysis with Varimax rotation. Bartlett's test (χ^2 [36, $N = 103$] = 162.98, $p <$ .000) was large and significant and the Kaiser-Meyer-Olkin measure (0.75) was greater than 0.60, therefore the factorability of the data was adequate. Eigenvalues for the first six components were 2.849, 1.337, 1.105, .919, .709, and .698 respectively, suggesting that three factors adequately described the data. These three factors accounted for 58.80% of the variance. Factor 1 can be referred to as visual memory because the three visual tasks loaded on this factor. It accounted for 31.66% of the variance. Factor 2 (verbal memory) accounted for 14.85% and Factor 3 (spatial memory) 12.28%. Letter orientation loaded on the visual factor rather than the spatial factor. Rotated factor loadings are included in Table 5.4. It is important to note that according to Stevens' (1996) criteria for assessing the significance of factor loadings, all the loadings displayed in bold face are statistically significant. Stevens' suggested that sample size needed to be considered when interpreting factor loadings and suggested that critical values for significance testing should be doubled. In this case, for a sample size of 100 (102) Steven's critical value of .256 would become 2(.256) = .512 (see Stevens, 1996, p. 371 for a table of critical values). Therefore, only factor loadings over this value would be interpreted as being statistically significant.

Because of the number of significant between construct correlations, the factor structure of the data were also analysed with principal components analysis with oblique rotation (direct Oblimin). The results of this analysis were comparable to the analysis using orthogonal rotation. The component correlation matrix revealed that the correlations between the factors were all below 0.26.

Table 5.4

Factor Solution from Principal Components Analysis with Varimax Rotation

Task	Factor 1	Factor 2	Factor 3
Polygons	**.797**	.008	.130
Matrices	**.696**	.005	.193
Visual *n*-back	**.695**	.002	.108
Arithmetic	.123	**.710**	.126
Consonants	.243	**.721**	.161
Verbal *n*-back	.009	**.720**	.002
Dot Memory	.001	.001	**.897**
Spatial *n*-back	.227	.234	**.707**
Letter Orientation	**.584**	.205	.390

5.5 Discussion

The present study was designed to examine the reliability and validity of a number of verbal, visual and spatial memory tasks. The main findings were that (1) all tasks showed adequate to good test-retest reliability, (2) a number of the tasks were intercorrelated, (3) three factors (visual, verbal, and spatial) emerged from the data, and (4) the letter orientation task loaded on the visual factor rather than the predicted spatial factor. Each of these findings will be discussed in turn.

The results showed that all the tasks had quite good temporal stability with reliability coefficients ranging from a low of 0.51 for letter orientation to a high of 0.89 for the arithmetic task. The means for performances on all tasks, except the arithmetic task, were slightly higher at retest than at test, suggesting that there may have been practice effects operating. This possibility was explored using a number of paired-sample *t*-tests. The results of these tests showed that the differences in the means for all the tasks, except the dot memory task, were not significantly different. Thus it appears that there may have been a practice effect for this task. Lemay, Bédard, Rouleau and Tremblay (2004) argued that task scores can show a practice effect and still have high test-retest reliabilities if those who scored highly on a task at test scored highly on the same task at retest. While this was the case for a number of participants on the dot memory task in the present study, there were also a number with low scores at test who showed considerable improvement in scores at retest. For example, one participant's score increased from 10 at test to 17 at retest. This would suggest that dot memory task performance was confounded by practice effects. Why the two weeks allowed before retest was sufficient for all the other tasks but not dot memory is unclear and certainly requires further investigation. One possibility is that participants developed strategies to remember the locations of the dots during the first testing and then used these strategies at retest.

The second main finding of the present study related to the intercorrelations between the tasks. It is possible that the relationships among the verbal, visual and spatial tasks reflect the fact that the verbal, visual and spatial working memory systems, although distinct, are also highly interrelated at the level of the central executive (Park, et al., 2002). So, while the tasks were assessing either phonological loop or visuo-spatial sketchpad functioning, they also likely required processes from the central executive. Central executive involvement in the tasks would support the claim that there is little distinction between visual and spatial working memory and short-term memory tasks (Miyake et al., 2000).

Central executive processes may also have been necessary because the number of items to-be-remembered (six) exceeded the capacity of the various slave systems. Evidence for this claim can be found in participant performance levels which were at or below 50% for all tasks. For the spatial and visual *n*-back tasks, performance was only at 29.7% and 29.9% correct respectively. Verbal memory reportedly has a capacity limit of about five to nine items (Miller, 1956) for short-term memory tasks, although Cowan (2001) argues that the capacity limits of verbal short-term memory may only be three to five items. It is not clear, however, what the capacity limits of verbal memory are when working memory tasks are used rather than short-term memory tasks. One would expect that the figure would be less than that found with short-term memory tasks because participants need to manipulate the information as well as remember it. Judging by the results of the present study, it appears as though this figure may only be about three to four items. However, Baddeley (1986) has argued that central executive involvement in verbal tasks that exceed the capacity of the phonological loop serves to increase the number of items that can be remembered. If this is the case, then capacity of the phonological loop for the tasks used in this study must be limited to one to two items and this is increased to three to four items with the help of central executive processes.

Capacity of the visuo-spatial system has been reported to be about three or four items (Alvarez & Cavanagh, 2004; Luck & Vogel, 1997; Song & Jiang, 2006; Vogel & Machizawa, 2004) and the present results are consistent with these findings. Others have suggested that retaining a single visual or spatial item can place demands on the central executive (Goldman-Rakic, 1992). Thus, the set size of six used in this study may have been beyond what an individual can remember regardless of type of information and regardless of central executive involvement. A memory set of four items may be more appropriate for future research, particularly when working with older adults.

The internal structure of the data revealed three independent factors, consistent with Baddeley and Hitch's (1974) working memory model, which accounted for almost 60% of the variance. Factor one was interpreted as being a visual memory factor because it comprised the three tasks designed to assess visual memory, polygons, matrices, and visual *n*-back, as well as one spatial task, letter orientation. The loading of letter orientation on the visual factor is not totally surprising given that the task involved the presentation of a number of letters in varying orientations. Participants needed to remember the letter and its orientation. It is also highly likely that this task involved more of a visual component than a spatial one because participants could simply retain a visual representation of the letters. It is also possible that participants verbally encoded the stimuli by saying, for example, the letter "A" upside down, despite the inclusion of articulatory suppression. The significant correlation between the letter orientation task and two of the verbal tasks, arithmetic and consonants, suggests that this may have been the case. Further, because of the highly over-learned nature of letters, it is possible that participants formed visual representations of the letters and used verbal encoding to recall the orientations. As a result, letter orientation in its present form is not an ideal spatial working memory task.

The second factor can be interpreted as being a verbal memory factor because the three verbal tasks, arithmetic, consonants, and verbal *n*-back, all loaded onto this factor. The final factor, the spatial memory factor comprised the dot memory task and the spatial *n*-back task. Similar to visual memory, the loadings for these two factors were all significant according to Steven's (1996) criteria. It appears therefore that the tasks used in this study, apart from letter orientation, were measuring three different constructs as would be predicted by Baddeley and Hitch's working memory model.

5.5.1 Conclusion

To conclude, all but one of the tasks used in this study appear to be reliable and valid indicators of the working memory construct that they were designed to measure. Eight of the nine tasks used were found to have adequate test-retest reliabilities and construct validity. The exception, of course, was letter orientation which apparently taps visual memory rather than spatial memory. It appears therefore that verbal, visual and spatial working memory can be measured as distinct processes using these tasks, making them ideal tasks to assess age-related differences in working memory processes.

However, it would be beneficial to re-examine these psychometric properties using a different, larger sample and a smaller set size.

There was evidence of intercorrelations between some of the different types of memory tasks that may have reflected central executive processing. Given that working memory tasks were used to assess verbal memory and that visual and spatial short term memory tasks are thought to be equivalent to working memory tasks, central executive processes would be expected to be involved in performance on these task. Further, it is possible that the set size of six used for these task was beyond the capacity limits of each of the different types of memory systems. As a result, a set size of four will be used in Experiment Three which examines the nature of age-related changes in working memory processes.

CHAPTER 6

Age-Related Changes in Verbal, Visual and Spatial Working Memory Processes: The Same or Different?

Experiment Three

6.1 Chapter Introduction

One of the major advantages of using reliable and valid measures of hypothetical constructs is that it allows us to discriminate between the different constructs. For example, because the tasks discussed in the previous chapter have been shown to be relatively reliable and valid, one should be able to use them to examine individual differences in verbal, visual and spatial memory performance with increased confidence in the conclusions that may be drawn. The current chapter examines age-related differences in each of the different types of memory using these tasks. Do each of the different types of memory change as a result of increased age? If so, do they all change at the same rate?

First a summary of the relevant literature, which was discussed in detail in Chapter 3, will be provided, followed by a discussion of the methodology used to examine age-related differences in verbal, visual and spatial memory. The results of the study are presented in the next section of the chapter which ends with a discussion of the results and the conclusions drawn from the results.

6.2 Age-related Differences in Verbal, Visual and Spatial Working Memory

As was discussed in Chapter 3, Section 3.2, age-related differences in cognitive functioning are mediated, in part, by age-related differences in working memory. Previous research in this area was reviewed in Chapter 3, but the main points from that research will be summarised here in order to highlight a number of issues relevant to the current study.

There seems no doubt that verbal working memory declines as a result of increasing age. Age-related declines in the amount of verbal information a person can remember are consistently reported in the literature (see for example, Park et al., 1996). Even though deficits in performance are greater on verbal working memory tasks than they are on verbal short-term memory tasks, both types of tasks are affected by age. For instance age-related decrements have been found on the reading span task (Meguro, et al., 2000; Park et al., 1996), operation or computation span tasks (Salthouse & Babcock, 1991), and on the forward and backward versions of the digit span task (Grégoire, & Van der Linden, 1997; Hester, et al., 2004; Park et al., 1996). While there is general consensus about the effects of age on verbal memory, there is no agreement about whether visual and spatial memory decline with increased age.

Consistent age-related changes have been found on tasks that assess memory for combined visual and spatial features, in other words, on tasks that require feature binding (Mitchell et al., 2000). However, the literature offers contradictory findings about whether age-related decrements occur when visual and spatial memories are tested separately. Age-related differences have been reported for spatial memory with Jenkins et al. (2002) showing that older adults have lower memory spans than younger adults on a location span task. Similarly Park et al. (2002) reported differences in younger and older adult's memory for both the forward and backward versions of the Corsi blocks task. Further, a secondary analysis of the Wechsler Memory Scale (3rd Edition) revealed age-related differences on the forward and backward versions of a spatial span task (Hester et al., 2004).

In contrast to these results, Olson et al. (2004) found no difference between younger and older adults spatial memory on a change detection task. However, Olson and colleague's task involved simultaneous presentation of the stimuli whereas the research mentioned previously used sequential presentation. By simultaneous presentation it is meant that all the items in the memory set were presented together rather than one at a time as in sequential presentation. The problem with simultaneous presentation in spatial memory studies is that it is possible for the locations to be encoded as a single gestalt figure (Vogel, et al., 2001) and therefore visual memory processes may be utilised by participants rather than spatial memory processes. Hence, it is likely that Olson et al’s results reflect visual memory and not spatial memory.

The idea that visual memory is unaffected by age is consistent with the work of Sekuler et al. (2005) who found no difference between younger and older adults performance on a visual recognition task using sinusoidal gratings as stimuli. However, a study by Leonards et al. (2002) reported conflicting results. Leonards and colleagues found age-related declines on tasks that assessed visual memory for faces and doors. Moreover, a review of the literature by Smith and Park (1990) found age-related declines in visual memory for doors and abstract drawings.

Not only is there a lack of agreement among researchers as to the effects of age on visual and spatial memory, there is relatively little research on visual memory and age. Furthermore, previous research on visual memory suffers from a number of methodological problems which require consideration. For example, in behavioural research visual memory is typically assessed using recognition tasks while verbal and spatial memory are assessed using recall tasks. If recall tasks are more age-sensitive than recognition tasks, as suggested by Craik and McDowd (1987), then the lack of age-related impairment reported by some may reflect the difference between recall and recognition rather than visual memory processes. Moreover, can one or more importantly should one, compare the results of studies that use recall tasks to the results of studies that use recognition tasks? Because visual memory tasks are typically recognition tasks, verbal, visual and spatial memory were examined using recognition tasks in the present study. Further, recognition tasks can be used in neurophysiological research more easily than recall tasks can. Using recognition tasks to test each of the different types of memory will enable them to be tested under the same conditions, thereby better allowing comparisons between the results.

Another potential problem with previous research in the visuo-spatial domain is that the majority of researchers have not controlled for the finding that people are likely to attach verbal labels to visual, and possibly spatial, stimuli as demonstrated in Experiment One (see Chapter 4) and as suggested by Bahrick and Boucher (1968) and others (see for example, Postle et al., 2005; Simons, 1995). The one possible exception is the work by Sekuler et al. (2005) who used sinusoidal gratings as to be remembered stimuli. It is highly unlikely that participants could attach verbal labels to these stimuli because it would be extremely difficult trying to find any resemblance between the gratings and real world objects. The current study also uses stimuli that are considered difficult to verbally label, for example, abstract polygons (Vanderplas & Garvin, 1959) and matrix patterns (Wilson, et al., 1989). However, as shown by the results of Experiment One, people still apparently tried to attach verbal labels to matrix patterns despite the difficulty in doing so. Stewart (2002) found a similar result with abstract polygons. The results of Experiment One also revealed that participants were using verbal labels to remember spatial locations, although to a lesser extent than they were used to remember matrix patterns. Therefore, to minimise the likelihood that participants are verbally labelling the visual and spatial stimuli in the current study, an articulatory suppression task will be included during the encoding stage of each of the tasks

As has been shown, the cognitive aging literature offers contradictory evidence about the effects of increased age on visual and spatial memory performance. There is also conflicting evidence as to whether verbal, visual and spatial memory processes are equally or differentially affected by increased age. Early research in this area found that the ability to process visuo-spatial information was affected by age to a greater extent than the ability to process verbal information (Tubi & Calev, 1989). These findings have been replicated in more recent research with Schaie and Willis (1993) reporting greater age-related changes in visuo-spatial processing speed tasks than in verbal processing speed tasks. Jenkins et al. (2000) and Myerson et al. (1999) provided evidence that visuo-spatial working memory tasks are also more sensitive to increased age than verbal working memory tasks. In contrast, Salthouse (1995) reported that verbal and spatial memory showed equivalent rates of change across the lifespan in a sample ranging in age from 18 to 88 years. Similarly, Park et al. (2002) used a range of verbal and spatial working memory, short-term memory, and long-term memory tasks to show that verbal and spatial processes were equally affected by increased age.

The task used by Jenkins et al. (2000) to assess visuo-spatial working memory, the location span task, was a spatial task not a visual task and therefore these findings cannot be generalised to the visual domain. The use of spatial tasks to assess visuo-spatial working memory appears to be a common practice in the cognitive aging literature with very few studies published that have assessed visual memory independently of spatial memory. One study that did so through using faces and doors as the to-be-remembered stimuli, found that visual memory was more age-sensitive than verbal memory (Leonards et al., 2002). However, the only study that could be located that has directly compared verbal, visual and spatial memory was conducted by Shaw et al. (2006) and as has been mentioned, it is difficult to draw any strong conclusions from this work because of the restricted age range of the sample. Therefore, there is no clear evidence as to whether verbal, visual and spatial memories are differentially affected by age or not.

6.2.1 Summary and aims

To summarise, the literature shows that age-related declines are evident in verbal memory and to a lesser extent spatial memory. It is difficult to draw any strong conclusions from the current literature as to the effects of increased age on visual memory. It is also unclear whether verbal, visual and spatial memories are equally or differentially affected by age with different researchers reporting different findings. It is thus possible that the conflicting results stem from methodological differences such as the use of recognition versus recall tasks. It is also likely that verbal coding strategies may have been used by participants in visual and spatial tasks. In addition, very little research has compared verbal, visual and spatial memory performance across the adult lifespan. Therefore, the aim of the present study was to examine age-related differences in verbal, visual and spatial memory using the tasks from Experiment Two. The study aimed to answer the following questions: Do verbal, visual and spatial memories change as a function of increased age? If so, do they show differential or equivalent rates of change?

6.3 Methods

6.3.1 Participants

The present study comprised 201 participants, 139 females and 62 males, aged between 18 and 80 years (*M* = 44.95; *SD* = 21.08) with normal or corrected-to-normal vision. Ninety-four participants were first- and second- year university undergraduates at James Cook University, Townsville Australia, while 107 were community dwelling residents from the Townsville district who were recruited via advertisements in the Townsville *Bulletin* and via an interview with the local Australian Broadcasting Commission (ABC) radio. Participants were grouped into one of three age groups depending on age (see Table 6.1). Those between the ages of 18 and 39 years formed the young age group (59 females and 17 males), those between the ages of 40 and 59 years the middle age group (41 females and 19 males), and those over 60 years the older age group (39 females and 26 males). These age groups are consistent with those from previous research (see Meguro et al., 2000; Salthouse, 1995).

6.3.2 Materials

All tasks and task instructions were presented on either an 800 MHz Novis Pentium III computer or a Toshiba Pentium IV laptop computer. A custom made program controlled stimulus presentation and recording of participant responses for all tasks.

Health status was assessed using a health status questionnaire developed by Christensen, Moye, Armson, and Kern (1992). The questionnaire included 36 questions relating to medical factors that are likely to impact on cognitive performance (included in the Appendix). Participants were given a score of one for each question to which they responded yes. Therefore, health status was determined by the number of items marked ‘yes’ on the questionnaire. The health status questionnaire also included questions relating to age, gender, number of prescribed medications taken per day, and level of formal education in years (total education level included number of years completed at primary, secondary and tertiary levels).

6.3.3 Memory tasks

Verbal memory was assessed using three tasks (described in detail in Chapter 5, Section 5.3.3), an arithmetic task, a consonant task, and a verbal *n*-back task. Visual memory was assessed using an abstract polygon task, matrix pattern task, and a visual *n*-back task (see Chapter 5, Section 5.3.4), while spatial memory was assessed using a dot memory task, a spatial *n*-back task (see Chapter 5, Section 5.3.5) and a letter location task. Letter location was used to replace letter orientation which was shown to tap visual memory processes rather than spatial memory processes in Experiment Two. In the letter location task, random letters of the alphabet were presented in random locations on a 7×7 non-visible matrix. Participants’ task was to remember the location of the letters, not the letters themselves. As with all the other tasks, response criteria involved clicking the computer mouse on the items from the memory set which appeared on random locations within the 7×7 non-visible matrix on the computer screen with 16 distracters.

6.3.4 Processing speed tasks

Processing speed was assessed using letter comparison, pattern comparison, and digit-symbol comparison tasks. A number of tasks have been used to measure processing speed, including coding-type tasks such as the digit-symbol substitution task, a subtest of the Wechsler Adult Intelligence Scale (WAIS; Wechsler, 1997). In the digit-symbol task, specific symbols are associated with specific digits. Participants are required to match the correct symbol with the correct digit. Processing speed tasks are defined as tasks that would allow for all items to be completed correctly if one is given ample time to complete the task (Piccinin & Rabbitt, 1999). Coding-type tasks fit this definition; however, studies have shown that they are not pure measures of processing speed because they also include a memory component (Lindenberger, et al., 1993; Piccinin & Rabbitt, 1999). It is possible for participants to learn the digit-symbol combinations after repeated trials on the tasks, thereby facilitating performance on the later trials. Processing speed tasks such as letter comparison and pattern comparison (Salthouse & Babcock, 1991), on the other hand, do not include a memory component. These tasks involve the presentation of letter or pattern pairs and participants need to determine whether or not the pairs are identical. Each trial contains a different set of letters or patterns, thus there is no possibility of learning specific combinations. As a result, letter comparison and pattern comparison are probably better able to determine processing speed than coding-type tasks are. Hence it was decided that all processing speed tasks should have the same requirements.

Letter comparison involved the presentation of randomly selected consonants arranged in sequences of three, six, or eight consonants in each of the pairs. The pairs were either identical in that each of the consonants in one of the pair was presented in the exactly the same order as the other of the pair (e.g. DLM DLM), or they were different in that some, or all of the consonants in the second of the pair were different than those of the first (e.g. DLM DYN). Same or different pairs could occur with equal occurrence. Pairs were presented side by side on the centre of the screen and remained there until the participant pressed one of the designated response keys.

Pattern comparison was the same as letter comparison except the stimuli were line patterns. Patterns were constructed using three, six, or eight lines (see Figure 6.1 for examples of patterns created using three lines). Again pairs of line patterns were presented side by side on the centre of the screen and participants needed to determine whether the patterns were the same or different. Response criteria were the same as for letter comparison. Digit-symbol comparison was also the same as for letter comparison except the pairs were made up of random combinations of digits and symbols, for example, 2Σβ 41Ω

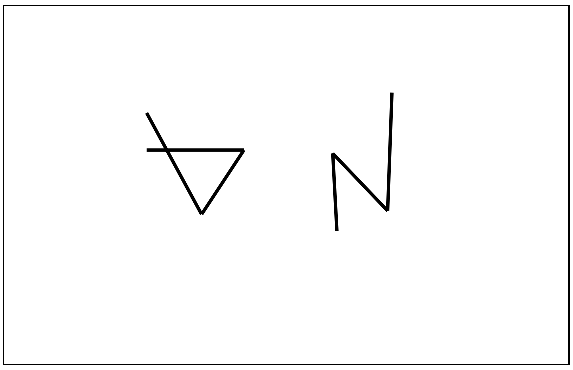

Figure 6.1. Example of types of stimuli used in pattern comparison task.

6.3.5 Procedure

After obtaining ethics approval, participants were either tested in the Cognitive Sciences Laboratory, School of Psychology, James Cook University, or in a quiet place in their own homes. Informed consent was obtained before testing began. All participants completed all tasks with testing taking between 60 to 90 minutes. Participants were free to take a break at any time during testing. Testing always began with the processing speed tasks followed by the memory tasks. Order of presentation of type of processing speed task was counterbalanced and then order of presentation of sequence size within each type of processing speed task was counterbalanced. For the processing speed tasks pairs of items were presented side by side on the centre of the screen. There was one 30 second practice trial at the start of the tasks. Participants were presented with as many pairs at each level as they could respond to within the 30 seconds. Each time a response was made to one pair of items a new pair of items would appear on the screen. Response criteria involved pressing the number ‘1’ key on the computer keyboard if the pairs were identical and the number ‘2’ key if they were different. On the laptop the ‘j’ key was used if the pairs were identical and they ‘k’ key if they were different. These keys were chosen because on the laptop they corresponded to the number ‘1’ and ‘2’ key, respectively, of a normal numerical keyboard.

Order of presentation of the type of memory was counterbalanced across participants as were the individual memory tasks. Visual and spatial memory tasks included an articulatory suppression task which involved repeating the syllable ‘blah’ out loud during the encoding stage of the tasks. Suppression was included to minimise contributions from the verbal memory system to performance on the visual and spatial tasks and adherence to the suppression was monitored by the experimenter.

6.4 Data Analysis

All data were analysed using an alpha level of 0.05. One-way ANOVAs were used to determine whether there were differences between the different age groups on measures of health status, level of education, and number of prescribed medications taken per day. Because a large number of participants reported no health problems and did not take any medication, the data for these variables were positively skewed. Consequently, Dunnett’s T3 test was used for post hoc comparisons for these data. Data for level of education were normally distributed, so Scheffe’s test was used for post hoc analysis for these data. To determine whether young, middle, and older aged groups differed on processing speed and accuracy on processing speed tasks, one-way ANOVAs were again used. Post hoc comparisons were conducted using Scheffe’s test. A mixed 3 (task: verbal, visual, spatial) x 3 (age group: young, middle, older) ANOVA was used to answer the question as to whether or not there was a change in verbal, visual and spatial memory performance across the adult lifespan. Task was used as a within-subjects variable while age group was the between-subjects variable.

Bivariate correlations were conducted to examine the relationship between the variables. A series of simple regression analyses were conducted to determine whether or not age was related to each of the different types of memory. These regressions also allowed for an examination of whether or not age was related to the different types of memory to the same extent. Because processing speed has been shown to mediate a large portion of the age-related variance in working memory tasks in previous research (for example, Salthouse, 1993, 1994a; 1995), regressions were conducted using both processing speed and verbal, visual and spatial memory. These regressions were conducted in an effort to determine whether speed acted as a mediator of the age-related variance in each of the different types of memory. Finally, to determine the extent of the relationship between age and each of the different types of memory, while controlling for other factors that have been shown to be related to cognitive functioning across the adult lifespan, for example, processing speed, health status, level of education, and number of prescribed medications taken per day, multiple regressions analyses were conducted using these variables as predictor variables if they were shown to be correlated with the different types of memory. These analyses again allowed for an examination of the difference or equivalence of the effects of age on verbal, visual and spatial memory across the adult lifespan.

6.4 Results

Means and standard deviations of ages in each of the age groups are presented in Table 6.1 as are the percentages of females in each age group. Means and standard deviations for health status, level of education, and number of medications taken each day were calculated and are also presented in Table 6.1. Health status scores ranged from zero to 8 for the total sample. For the young age group health status ranged from zero to 4, the middle age group from zero to 5, and the older age group from zero to 8. Number of medications taken per day ranged from zero to 10 for the total sample, from zero to 2 for the young age group, zero to 8 for the middle age group, and zero to 10 for the older age group. Level of education ranged from 6 to 25 years for the total sample, 9 to 17 years for the young age group, 10 to 20 years for the middle age group, and 6 to 25 years for the older age group.

One-way ANOVAs were conducted to determine whether there were differences between the age groups on measures of health status, level of education, and number of medications per day. The results of these analyses showed that there was a significant difference in health status, $F\ (2,198) = 7.95$, $p < 0.05$, $\eta^2 = 0.07$; level of education, $F\ (2,198) = 6.59$, $p < 0.05$, $\eta^2 = 0.06$; and number of medications per day, $F\ (2,198) = 50.200$, $p < 0.05$, $\eta^2 = 0.34$, for the different age groups. Post hoc comparisons using Dunnett T3 revealed a significant difference between the mean scores on health status between the young and middle aged groups ($p < 0.05$) and between the young and older age groups ($p < 0.001$), but the difference between the middle and older age groups was not significantly different ($p > 0.05$). Mean number of medications taken per day was significantly different between the young and middle aged groups ($p < 0.05$), between the young and older aged groups ($p < 0.001$), and between the middle and older aged groups ($p < 0.001$). For level of education, post hoc comparison using the Scheffe test revealed that the difference between the means for the young and middle aged groups was not significantly different ($p > 0.05$), nor was the difference between the young and older aged groups ($p > 0.05$), while the difference between the middle and older aged groups was significantly different ($p < 0.05$).

Table 6.1

Demographic Characteristics of Total Sample and Age Groups

	Sample (*n* = 201)	18 – 39 (*n* = 76)	20 – 59 (*n* = 60)	60 – 80 (*n* = 65)
Age	44.95	21.29	48.03	69.75
	(21.08)	(5.03)	(4.66)	(6.36)
% Female	69.2	77.6	68.3	60.0
Education	13.22	13.31	14.11	12.29
	(2.90)	(1.21)	(2.75)	(3.99)
Health	0.83	0.37	0.97	1.29
	(1.37)	(0.85)	(1.37)	(1.73)
Medications	1.27	0.11	0.87	3.02
	(2.15)	(0.39)	(1.75)	(2.56)

Note. Standard deviations are in brackets.

Data for processing speed tasks included both reaction time data and accuracy scores. A person's processing speed was considered to be an average of the time they took to correctly respond to the pairs across tasks and sequences. Accuracy scores were calculated as the number of pairs correctly identified as being the same or different across the three sequence sizes (3, 6, and 8) for each of the different processing speed tasks (letter comparison, pattern comparison, and digit-symbol comparison), divided by the number of pairs presented per person. These figures were then converted into percentages by multiplying them by 100. Means and standard deviations for processing speed tasks, and total processing speed and accuracy are presented in Table 6.2.

One-way ANOVAs were conducted to determine whether there was a difference in processing speed and accuracy between the different age groups. The results of these analyses show that there was not a significant difference in accuracy levels on the processing speed tasks between the different age groups ($p > 0.05$). There was a significant difference in processing speed, F (2,198) = 30.54, $p < 0.001$, $\eta^2 = 0.20$. Scheffe post hoc comparisons revealed significant differences between the young and middle age groups ($p < 0.001$), the young and older age groups ($p < 0.001$), and between the middle and older age groups ($p < 0.001$). These differences are displayed graphically in Figure 6.2.

Table 6.2

Means and Standard Deviations for Reaction Times and Accuracy on Processing Speed Tasks, and Total Processing Speed and Accuracy Means and Standard Deviations for Young, Middle, and Older Age Groups

	Young (18-39)	Middle (39-40)	Older (60+)
Letter Comparison			
Reaction Time (msec.)	1292.07	1562.08	1769.85
	(325.82)	(453.56)	(467.99)
Accuracy	96.84%	97.38%	96.31%
	(2.95)	(2.54)	(5.55)
Pattern Comparison			
Reaction Time (msec.)	1111.82	1354.90	1603.13
	(219.84)	(424.99)	(516.17)
Accuracy	95.54%	97.96%	95.39%
	(2.62)	(2.56)	7.99)
Digit-Symbol Comparison			
Reaction Time (msec.)	1393.06	1693.51	1958.59
	(388.74)	(618.63)	(580.02)
Accuracy	96.83%	96.87%	96.27%
	(2.54)	(3.09)	(6.60)
Reaction Time Total			
(Processing Speed)	1265.65	1563.83	1777.19
	(256.89)	(466.90)	(434.45)
Accuracy Total	96.41%	97.40%	95.99%
	(1.99)	(1.92)	(5.66)

Note: 18-39 *n* = 76; 40-59 *n* = 60; 60+ *n* = 65. Standard deviations are in brackets and reaction times are recorded in milliseconds.

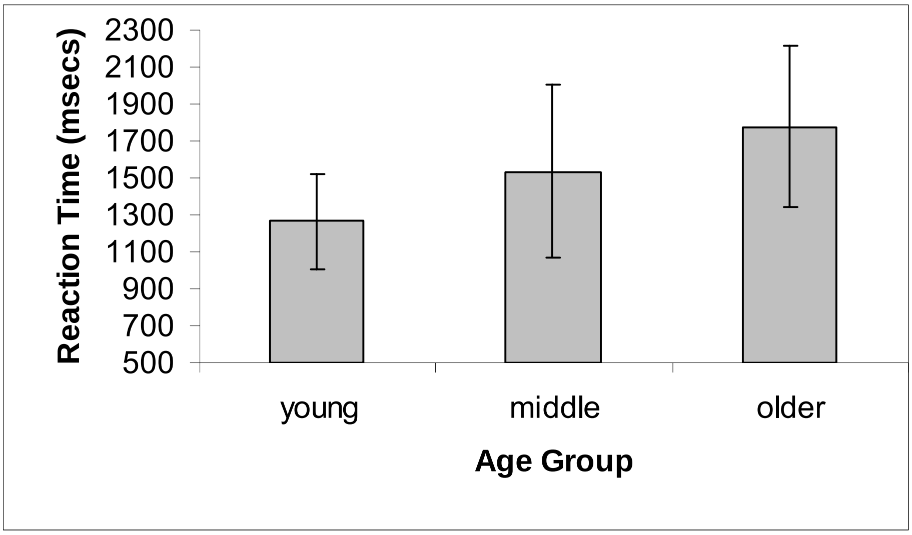

Figure 6.2. Comparison of processing speed between young, middle, and older age groups.

Memory scores were calculated by adding the total number of items correctly recognised across trials, giving a total possible score of 20 for each task. Composite memory scores were then calculated for each type of memory, verbal, visual and spatial, by adding together the scores out of 20 for each of their respective tasks. Thus, the verbal memory score was calculated by adding total scores for the arithmetic, consonants, and verbal *n*-back tasks, visual memory was a composite of the polygon, visual *n*-back, and matrix patterns tasks, and spatial memory of dot memory, letter location, and the spatial *n*-back task. Mean verbal memory score for the whole sample was 33.43 (*SD* = 6.89), for visual memory *M* = 28.32 (*SD* = 4.99), and for spatial memory *M* = 33.46 (*SD* = 5.92). Means and standard deviations for the all of the memory tasks for each age group are displayed in Table 6.3.

Table 6.3

Means and Standard Deviations for Verbal, Visual and Spatial Memory Tasks by Age Group

	Young (18-39)	Middle (40-59)	Older (60 - 80)
Arithmetic	11.96 (2.34)	12.82 (2.43)	10.95 (3.06)
Consonants	12.59 (2.19)	13.02 (2.55)	10.08 (2.63)
Verbal *n*-back	10.08 (2.49)	10.70 (2.90)	8.14 (2.84)
Verbal Memory	34.63 (5.17)	36.53 (6.33)	29.17 (7.19)
Polygons	10.88 (2.27)	10.75 (1.87)	9.68 (2.30)
Visual *n*-back	5.89 (2.13)	7.53 (2.50)	6.65 (1.42)
Matrix Patterns	11.53 (2.09)	11.87 (2.30)	10.30 (2.66)
Visual Memory	28.32 (4.41)	30.15 (5.44)	26.63 (4.67)
Dot Memory	13.29 (2.18)	13.20 (2.51)	11.06 (2.75)
Spatial *n*-back	6.71 (2.58)	7.98 (2.47)	6.98 (1.89)
Letter Location	15.30 (2.03)	13.92 (2.80)	11.75 (2.58)
Spatial Memory	35.30 (2.03)	35.10 (5.42)	29.80 (5.79)

Note. Standard deviations are included in brackets. 18-39 *n* = 76; 40-59 *n* = 60; 60 - 80 *n* = 65.

A mixed 3 (task: verbal, visual, spatial) x 3 (age group: young, middle, older) ANOVA was conducted to determine whether verbal, visual and spatial memory performance differed between the different age groups. Type of task was the within-subjects factor while age group was the between-subjects factor. The results of this analysis revealed a significant main effect of task, F (2, 396) = 84.23, MSE = 20.15, $p < 0.001$, $\eta^2 = 0.30$, and a significant task × age group interaction, F (2, 396) = 5.52, MSE = 20.15, $p < 0.001$, $\eta^2 = 0.05$. The main effect of age group was also significant, F (1,198) = 30.81, MSE = 50.29, $p <$ 0.001, $\eta^2 = 0.24$. Bonferroni corrected comparisons were conducted to determine the source of the interaction (see Figure 6.3). For verbal memory the difference between the young and middle age groups was not significantly different ($p > 0.05$), but the differences between the young and older ($p < 0.005$) and the middle and older age groups ($p < 0.005$) were significantly different. For visual memory there was no significant difference between the young and middle age group ($p > 0.05$) and the young and older age group ($p > 0.05$), but the difference between the middle and older age group was significantly different ($p < 0.005$). Finally, for spatial memory the difference between the young and middle age group was not significant ($p > 0.05$) while the differences between the middle and older age group ($p < 0.005$) and the young and older age group ($p < 0.005$) were both significantly different.

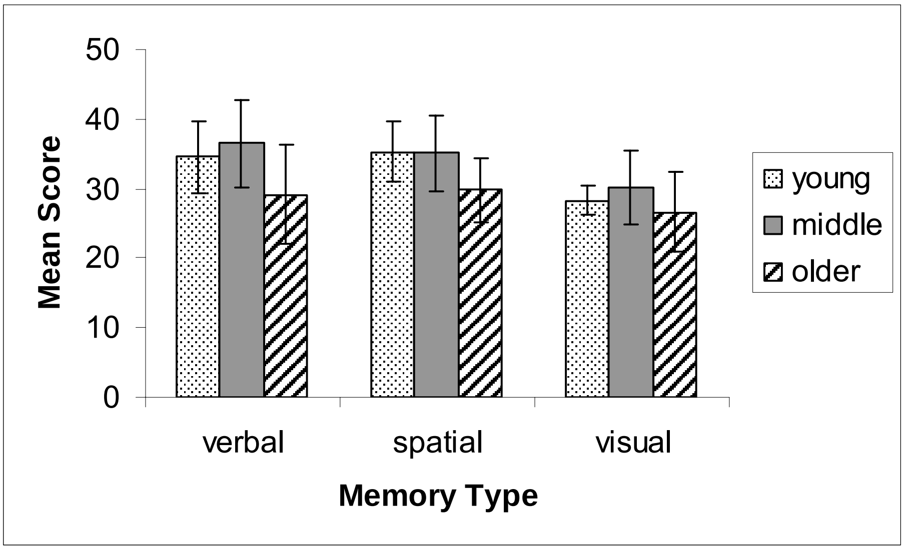

Figure 6.3. Comparison performance levels on verbal, visual and spatial memory tasks between young, middle and older age groups.

Correlations between age, health status, level of education, number of medications, processing speed and accuracy, and verbal, visual and spatial memory were calculated using Pearson's *r* and are reported in Table 6.4. Correlations between health status and verbal, visual and spatial memory were all below 0.20, as were the correlations between level of education and verbal, visual and spatial memory. As a result, these variables were excluded from further analyses. Data for the rest of the variables were examined for violations of the assumptions of multiple regressions before regression analyses were conducted. Assumptions of multicollinearity were not violated as tolerance values ranged from between 0.566 and 0.914 (all greater than 0.10) and variance inflation factors (VIF) ranged from between 1.094 and 1.768 (all below 10). Examination of the residual scatter plots and normality plots revealed no serious violation of the assumptions of normality, linearity, homoscedasticity, and independence of residuals. Mahalanobis distance for this data set was 31.37 and no cases fell above this figure, suggesting no serious problems with outliers.

Separate regression analyses were conducted to determine how much of the variance in verbal, visual and spatial memory performance was accounted for by age. The results of these analyses revealed that age explained 11% of the variance in verbal memory [$R = 0.34$, $F(1,199) = 25.47$, $p < 0.001$], approximately 3% of the variance in visual memory [$R = 0.17$, $F(1,199) = 5.58$, $p < 0.05$], and 16% of the variance in spatial memory [$R = 0.40$, $F(1,199) = 37.75$, $p < 0.001$]. Because speed of processing has been shown to be a significant predictor of age-related variance on working memory tasks, models were then analysed with both speed of processing and age as predictors of each of the different types of memory. The results of these analyses indicated that the model predicted approximately 14% of the variance in verbal memory, $R = 0.37$, $F(2, 198) = 15.58$, $p < 0.001$, approximately 8% of the visual memory variance, $R = 0.28$, $F(2,198) = 8.31$, $p < 0.001$, and 17% of the spatial memory variance, $R = 0.41$, $F(2,198) = 19.78$, $p < 0.001$. Standardised and unstandardised coefficient values and the corresponding *t*-test results are presented in Table 6.5.

Table 6.4

Correlations Between, Age, Health Status, Level of Education, Number of Medications, Processing Speed and Accuracy, and Verbal, Visual and Spatial Memory

	1	2	3	4	5	6	7	8	9
1. Age	1.00								
2. Health Status	0.30**	1.00							
3. Level of Education	-0.13	-0.17*	1.00						
4. Medications	0.56**	0.45**	-0.29**	1.00					
5. Processing Speed	0.51**	0.24**	-0.08	0.31**	1.00				
6. Accuracy	-0.08	-0.11	0.19**	0.03	-0.21**	1.00			
7. Verbal Memory	-0.34**	-0.12	0.19*	-0.29**	-0.30**	0.31**	1.00		
8. Visual Memory	-0.17*	-0.07	-0.07	-0.35**	-0.28**	0.24**	0.54**	1.00	
9. Spatial Memory	-0.40**	-0.04	-0.04	-0.29**	-0.28**	0.21**	0.22**	0.28**	1.00

Note. ** $p < 0.01$; * $p < 0.05$, both two-tailed.

Table 6.5

Results of Regression Analyses using Processing Speed and Age as Predictors of Verbal, Visual and Spatial Memory

	B	*SEB*	*β*	*t*
Verbal Memory				
Age	-0.081	0.249	-0.25**	-3.25
Processing Speed	-0.003	0.001	-0.17*	-2.27
Visual Memory				
Age	-0.008	0.019	-0.03	-0.43
Processing Speed	-0.003	0.001	-0.26**	-3.38
Spatial Memory				
Age	-0.098	0.021	-0.35**	-4.65
Processing Speed	-0.001	0.001	-0.10	-1.30

Note. ** $p < 0.001$; * $p < 0.05$.

The age-related variance on all the memory tasks was decreased when speed of processing was controlled for. For verbal memory the amount of variance explained by age was reduced to 5% ($p < 0.001$), for visual memory to a non-significant 0.08% ($p > 0.05$), and for spatial memory it was reduced to 9% ($p < 0.001$). These results suggest the possibility that speed of processing was acting as a mediator of the age-related variance in each of the different types of memory. Baron and Kenny (1986, p. 1176) argued that three conditions must be met before a variable can be considered a mediating variable: First, “variations in levels of the independent variable significantly account for variations in the presumed mediator.” In other words, age should be a significant predictor of speed in regression analysis. Secondly, “variations in the mediator significantly account for variations in the dependent variable” (p.1176). In this case speed should be a significant predictor of type of memory. Finally, (c) when controlling for speed, the previously significant relationship between age and type of memory should be no longer significant (full mediation), or significance should be reduced (partial mediation).

In the present study the relationship between age (independent variable) and speed of processing (mediator variable) was significant, $R^2 = 0.51$, $F(1,199) = 68.33$, $p < 0.001$. The relationship between speed of processing (mediator variable) and verbal memory (dependent variable) was significant, as it was for visual memory; however it was not significant for spatial memory (see Table 6.5). Finally, as was previously mentioned, the relationship between age and verbal memory was reduced, but was still significant, when controlling for speed of processing suggesting partial mediation. For visual memory the relationship with age was reduced to non-significant indicating full mediation of the age-related variance by speed of processing.

Significance of the mediation effects of speed of processing was examined using a test of significance developed by Sobel (1982). The results of these analyses showed that speed of processing partially mediated the relationship between age and verbal memory, Sobel's test statistic = 2.18, *p* = 0.03, and it completely mediated the relationship between age and visual memory, Sobel's test statistic = 3.05, *p* = 0.002. These mediated relationships are shown in Figures 6.3 (verbal memory) and 6.4 (visual memory).

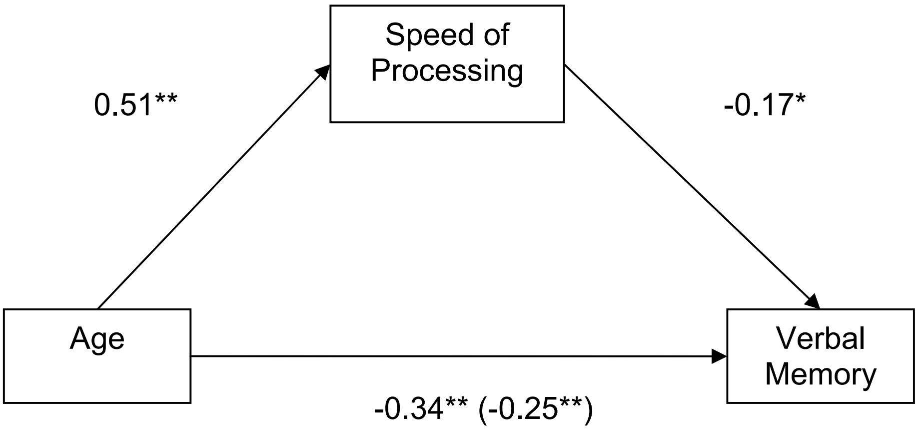

Figure 6.4. Standardised regression coefficients for the relationship between age and verbal memory as mediated by speed of processing. The regression coefficient between age and verbal memory after controlling for speed of processing is in brackets. ***p* < 0.001; **p* < 0.05.

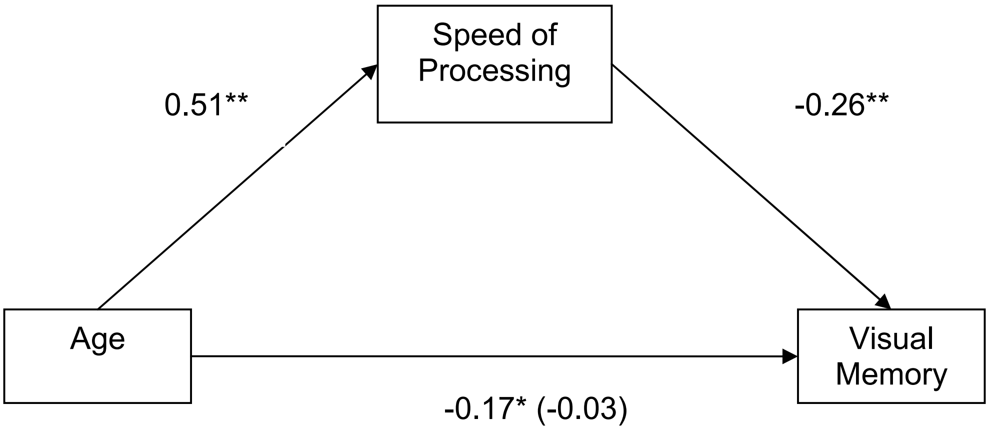

Figure 6.5. Standardised regression coefficients for the relationship between age and verbal memory as mediated by speed of processing. The regression coefficient between age and visual memory after controlling for speed of processing is in brackets. $**p < 0.001$; $*p < 0.05$.

Regression models were then examined that contained age, speed of processing, and number of medications per day. The model explained 15% of the variance in verbal memory, $R = 0.39$, $F\,(3,197) = 11.56$, $p < 0.001$, almost 17% of the visual memory variance, $R = 0.41$, $F\,(3,197) = 13.01$, $p < 0.001$, and 17% of the variance in spatial memory, $R = 0.41$, $F\,(3,197) = 13.61$, $p < 0.001$. The results of these analyses are presented in Table 6.6. As can be seen in the table, age (2%) and speed of processing (1%) made significant contributions to verbal memory variance. Speed of processing (5%) and number of medications (9%) were the strongest contributors to visual memory while age (5%) was the only variable to make a significant contribution to the variance in spatial memory.

Table 6.6

Results of Regression Analyses using Age, Number of Medications and Processing Speed as Predictors of Verbal, Visual and Spatial Memory

	B	*SEB*	*β*	*t*
Verbal Memory				
Age	-0.057	0.029	-0.17*	-1.98
Processing Speed	-0.003	0.001	-0.17*	-2.21
Medications	-0.452	0.254	-0.14	-1.78
Visual Memory				
Age	0.038	0.020	0.16	1.83
Processing Speed	-0.003	0.001	-0.25**	-3.27
Medications	-0.830	0.182	-0.36**	-4.55
Spatial Memory				
Age	-0.085	0.024	-0.30**	-3.52
Processing Speed	-0.0021	0.001	-0.10	-1.26
Medications	-0.238	0.215	-0.09	-1.10

Note. **$p < 0.001$; *$p < 0.05$.

Although the model tested above explained a significant portion of the variance in verbal, visual and spatial memory performance, there was a large amount of variance not explained for by this model. It is possible that central executive functioning may explain part of this variance. The *n*-back tasks used in the current experiment were quite difficult tasks and it is possible that they may have been tapping central executive resources more heavily than the other tasks[1]. Each of the *n*-back tasks loaded on verbal, visual, or spatial memory factors in Experiment Two, which suggests that they were tapping similar resources. However, the participants in Experiment Two were all below 56 years of age (*M* = 23.96; *SD* = 9.68) and it is possible that the factor structure may have been different if older adults were included in that study. Furthermore, it is likely that the *n*-back tasks did not load on a central executive factor because no other central executive tasks were included in Experiment Two. As a result, correlations between the three *n*-back tasks were calculated for each of the age groups. As can be seen in Table 6.7, the correlations between all the tasks increased during middle age but only the correlation between the visual and spatial tasks increased in the old age group. Because of the difference in correlations between these tasks in the different age groups, it was decided to run another series of multiple regressions using the *n*-back scores as a measure of central executive functioning in a model that also included age, processing speed, and number of medications per day. The results of these analyses revealed that the model explained 36% of the variance in verbal memory, $R = 0.60$, $F\,(4,196) = 27.38$, $p < 0.001$, 32% of the variance in visual memory, $R = 0.57$, $F\,(4,196) = 22.95$, $p < 0.001$, and 28% of the variance in spatial memory, $R = 0.53$, $F\,(4,196) = 19.06$, $p < 0.001$. As can be seen in Table 6.8, age (5%) and the central executive variable (25%) were the strongest contributors to verbal memory variance, and processing speed no longer made a significant

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[1] Alan Baddeley pointed out the possibility that the *n*-back tasks used in the current study may have been measuring central executive processes during the 4th International Conference on Memory in Sydney (July 2006) where a paper based on the results of the current study was presented.

contribution. For visual memory, processing speed (3%) and number of medications (3%) remained significant contributors, however the central executive variable (11%) accounted for a larger portion of the variance than each of these variables. Age (12%) was the strongest contributor to spatial memory variance, with the central executive variable (3%) also shown to be a significant contributor to this variance.

Table 6.7

Correlations between Verbal, Visual and Spatial n-Back Tasks for Young, Middle, and Older Age Groups.

	Verbal	Visual	Spatial
Young			
Verbal	1.00	0.26*	0.24*
Visual		1.00	0.30**
Spatial			1.00
Middle			
Verbal	1.00	0.38**	0.31**
Visual		1.00	0.34**
Spatial			1.00
Older			
Verbal	1.00	0.25*	0.21
Visual		1.00	0.48**
Spatial			1.00

Note. ***p* < 0.001; **p* < 0.05.

Table 6.8

Results of Regression Analyses using Age, Number of Medications, Processing Speed and a Central Executive Measure as Predictors of Verbal, Visual and Spatial Memory

	B	*SEB*	*β*	*t*
Verbal Memory				
Age	-0.070	0.018	-0.31**	-3.97
Processing Speed	-0.000	0.001	-0.004	-0.05
Medications	0.117	0.159	-0.05	-0.74
Central Executive	0.449	0.052	0.52**	8.71
Visual Memory				
Age	0.012	0.015	0.07	-0.85
Processing Speed	-0.002	0.001	-0.19*	-2.76
Medications	-0.363	0.131	-0.20*	-2.77
Central Executive	0.245	0.043	0.35**	5.74
Spatial Memory				
Age	-0.113	0.019	-0.47**	-5.78
Processing Speed	-0.000	0.001	-0.03	-0.41
Medications	-0.006	0.176	-0.003	-0.04
Central Executive	0.164	0.057	0.18*	2.87

Note. ***p* < 0.001; **p* < 0.05.

6.6 Discussion

A review of the literature on working memory and age showed that verbal memory declines with increased age. There has also been some support for the notion that spatial memory is sensitive to the affects of increased age but the results are not as clear as they are for verbal memory. Furthermore, little is known at all about the relationship between age and visual memory. Therefore, the present study aimed to examine whether verbal, visual and spatial memory all showed age-related differences and if so, whether that difference was equivalent across the adult lifespan or not.

Consistent with the results of some previous research (for example, Babcock & Salthouse, 1990; Meguro et al., 2000; Park et al., 1996), the present study found that verbal memory declined across the age groups. Although there was a slight increase in verbal memory scores between young adulthood and middle age the difference between these two groups was not significantly different. The difference in verbal memory performance between the young and older age groups, and between the middle and older age groups, however was significantly different.

Consistent with the results of previous research (Park et al., 1996; Babcock & Salthouse, 1990) processing speed was also shown to mediate a significant proportion of the age-related variance in verbal memory. It further mediated a significant proportion of the variance in visual memory. Interestingly, processing speed did not contribute to the age-related variance in spatial memory performance. It appears, at least for this sample, that processing speed is only important when we are processing verbal and visual information but not spatial information. However, it should be noted that the relationship between speed and verbal memory was reduced to non-significance when the central executive variable was included in the regression model. For visual memory, processing speed remained a significant contributor, but its contribution was reduced.

Consistent with previous research by Jenkins et al. (2000) and Park et al. (2002), the current study found that spatial memory decreased across age groups. Jenkins and colleagues did not test middle aged adults, however Park and colleagues tested participants ranging in age from 20 to 92 years. Decline was evident across the whole of the adult lifespan. In contrast, the results of the present study revealed no evidence of decrease in spatial memory performance between young adulthood and middle age, but a significant decrease in performance between the young and older age group and between the middle and older age group.

The results of the current study provide evidence for a decrease in visual memory after middle age. The difference in visual memory performance of the young adults was not significantly different than that of the older age group. Similarly young adults’ performance was not significantly different than that of middle aged participants. There was, however, evidence for an increase in performance in middle age which was then followed by a significant decrease in old age. While these results are consistent with those of Leonards et al. (2002), who found a decline in memory for faces and doors across the lifespan, they are also different in that Leonards and colleagues reported a decline that began at age 20 and continued up to age 69 years.

These researchers did not test participants past 69 years of age. In the current study, the decrease was not evident until after middle age, in this case after the age of 59 years. The results of the current study are also consistent with those of Sekuler et al. (2005) who found no decrease in performance between young and older adults in their visual memory for sinusoidal gratings. However, Sekuler and colleagues did not test middle aged participants, so it is not known whether a decline would have become evident between middle and old aged adults as was the case in the current study. It appears, however, that the decrease in visual memory found after middle age may not be age-related. Age was not a significant predictor of visual memory performance once variables such as processing speed, number of medications, and operation of the central executive were included in the regression model. Hence, the decrease in visual memory performance after middle age appears to be related to these other variables.

An interesting aspect of the results of the current study was the trend toward an increase in verbal and visual memory performance from young adulthood to middle age and the lack of difference in spatial memory performance between these two age groups. One needs to ask why the middle aged adults in this study performed at a level higher, or at the same level, as the young adults. A possible explanation could be that all of the middle aged adults who participated in this study were either in full time employment or full time study. As a result, increased performance may reflect a continuation, or increase, in cognitive activity during this time of life. Middle aged adults have been considered to be both competent and productive (Lachman, Lewkowicz, Marcus, & Peng, 1994) and are therefore likely to have increased, or at least maintained, the cognitive abilities they displayed in young adulthood. Indeed, Willis and Schaie (1999) argue that, based on data from the Seattle Longitudinal Study, a number of cognitive abilities reach a ‘peak’ in middle age, including vocabulary, verbal memory, inductive reasoning, and spatial orientation. Therefore, the typical negative attitude to reaching middle age may be unfounded. This view is supported by Miller and Lachman (2000) who found little evidence of decline on tests of processing speed, reasoning, and short-term memory. The results of the current study are thus in accord with those of Willis and Schaie and Miller and Lachman for verbal memory, and extend the results to the visual and spatial domains. The results of this study also highlight the need to include middle aged adults in studies of cognitive aging rather than just comparing young and older adults performance on cognitive tasks.

The results of the current study show that, contrary to the findings of Park et al. (2002) and Salthouse (1995), verbal, visual and spatial memory are differentially affected by age. Evidence for this conclusion can be found in the difference in the amount of variance in verbal, visual and spatial memory that was accounted for by age in regression analyses. Age made a significant contribution to spatial memory in all of the regression models, explaining 17% of the variance when used as a single predictor. In the model that included age, processing speed, and number of medications, age was the only variable to make a significant contribution to the variance on spatial memory, accounting for 5% of the variance. This percentage was increased to 12% when the central executive variable was added to the model. Age also made a significant contribution to verbal memory variance, explaining 11% of the variance when used as a single predictor, 2% when processing speed and number of medications were controlled for, and 5% when processing speed, number of medications, and central executive were controlled for. Although age made a significant contribution to visual memory variance when used as a single predictor (3%), it did not remain a significant contributor once processing speed, number of medications, and the central executive variable were included in the model. On the basis of these results it is difficult to conclude that verbal, visual and spatial memories are equally sensitive to the effects of increased age. Rather it appears that while increased age may lead to declines in verbal and spatial memory performance, it has little effect on visual memory performance.

It is interesting to note that the regression model that included age, processing speed, number of medications, and the central executive variable explained more of the variance in verbal, visual and spatial memories than did the model that did not include the central executive variable. These results suggest that central executive functioning was required when completing these tasks, but not to the same extent. The central executive variable explained 25% of the variance in verbal memory once age, processing speed, and number of medications was controlled for. This result is not surprising given that the verbal memory tasks were difficult working memory tasks. Of more interest, however, is the fact that the central executive variable explained 11% of the variance in visual memory and only 3% of the variance in spatial memory. Miyake et al. (2001) have argued that the visuo-spatial sketchpad is more closely linked to the central executive than is the phonological loop (also see Fisk & Sharp, 2003). Hence, visual and spatial short-term memory tasks require central executive processes in the same way that verbal working memory tasks do. The current results appear to support this assumption, however, it does appear that visual short-term memory tasks require greater central executive functioning than spatial short-term memory tasks do.

Another interesting result from the current study was that the number of prescribed medications a person takes a day is related to their performance on visual memory tasks. It is unclear why this is the case but it may be related to the novelty of the items used as visual stimuli (Helmes, 2006). However, the exact relationship between these variables requires further investigation and likely depends on the type of medication a person was taking. While the number of medications a person was taking per day was recorded in the current study the exact type of medications was not recorded and therefore it would not be appropriate to speculate on the nature of this relationship. What is also interesting is that medications were a predictor, where health status was not. This suggests that the effects may be due to untoward effects of the medication and not to the person's underlying health condition.

There are a range of factors that have been shown to be important mediators of age-related variance found on many cognitive tasks, including memory tasks (Park, 2000). For example, sensory functioning (Lindenberger

& Baltes, 1994; 1997) and exercise (Williams & Lord, 1997) have both been shown to affect cognitive performance. Participants in the current study were not asked whether they undertook any form of additional exercise activity and it is possible that the results partly reflected differences in level of physical activity. Future research in this area needs to take this into consideration. It is unlikely that sensory functioning played a significant role because all tasks used in this study were presented visually and all participants had normal or corrected-to-normal vision. It is doubtful that other types of sensory functioning, hearing for example, would have affected performance on these tasks. Moreover, all instructions were given verbally and presented visually to ensure participants understood what was required. That being said, it would be beneficial to include measures of sensory functioning in future research so that the relationship between these variables and performance on visually presented tasks can be examined more closely.

An important issue raised by the current results also needs to be discussed further. Performance levels of participants of all ages were poorer on the visual tasks used in this study as compared to performance levels on the verbal and spatial tasks. This finding would go some way to explaining the greater level of central executive functioning involved in the visual tasks as discussed above. It has been suggested that older adults' visual memory is affected by age to a greater extent than is verbal memory because they are less practiced at processing this type of information (Hester et al., 2004; Tubi & Calev, 1989). However, it would appear that adults of all ages are affected by the novelty of visual information, not just older adults. An alternative explanation is that younger adults’ performance on the visual tasks used in this study was affected because of the inclusion of the articulatory suppression task during the encoding stage of these tasks. Articulatory suppression would have minimised the possibility of attaching verbal labels to the visual memory stimuli, thereby forcing participants to rely more heavily on visual codes to remember them. Because people are so used to using verbal labels to remember visual information, what they are less practiced at doing is using visual codes alone and therefore performance is impaired under articulatory suppression conditions. These results emphasise the need to ensure we do all we can to minimise contributions from the verbal system when examining visual memory processes. Articulatory suppression allows us to do this and the contradictory results from previous research in this area may actually be because the tasks used in these studies were measuring different levels of verbal memory involvement.

6.6.1 Conclusion

Verbal and spatial memories show evidence of decline in older aged adults but there is very little difference between young and middle aged adults performance on spatial memory tasks. There is also very little evidence of a difference in visual memory performance between young and older aged adults; however, there is a significant difference between middle and older aged adults’ performance on the same tasks. Both verbal and visual memory show evidence of a peak in performance in middle age, hence it is important that this age group is included in cognitive aging studies.

Verbal, visual and spatial memories are not affected by age to the same extent. Age explains more of the variance in spatial memory than in verbal and visual memory regardless of whether other variables known to influence cognitive functioning, for example processing speed, central executive functioning, and number of medications per day, are included in the analysis or not. Processing speed, on the other hand, does not appear to contribute to spatial memory performance to the same extent as it does verbal and visual memory performance. Processing speed also acts as a mediator between age and verbal and visual memory but not spatial memory. However, the age-related variance in visual memory performance is reduced to below 1% once processing speed has been controlled for. In fact, age is not a significant predictor of visual memory performance at all with processing speed and number of medications explaining more of the variance in visual memory than age. However, the amount of variance explained by these two variables is reduced when a central executive variable is included in the analyses. Central executive functioning accounted for a significant proportion of the variance in verbal, visual and spatial memory performance. It appears therefore that the tasks used in the current study were tapping something other than slave system processes despite the fact that the visual and spatial tasks were short-term memory tasks. These results converge with Miyake et al's (2001) and Fisk and Sharp's (2003) findings that the visuo-spatial sketchpad is more closely linked to the central executive than is the phonological loop. In contrast to visual memory, age does make a significant contribution to verbal memory variance and to spatial memory variance but it does not explain as much of the variance in verbal memory as it does in spatial memory.

The results of the current study not only increase our understanding of the relationship between age and visual and spatial memory, they also highlight some very important methodological issues that cognitive aging researchers need to consider in future research. First, it is important that middle aged adults are included in cognitive aging research because some cognitive processes may actually increase rather than decline during this period. Hence, a decline that is not evident between young and older adults may become evident between middle and older age groups. Second, it is important that the relationship between each of the different types of memory and the central executive is considered when testing these different types of memory. Visual short-term memory tasks may be more similar, in terms of central executive involvement, to verbal working memory tasks than spatial short-term memory tasks are. Also, it is important that each of these different types of memory are included in studies examining age differences in working memory processes because it appears that the declines that are often reported as age-related may be the result of other factors, including central executive functioning and medication. Finally, it is important that researchers do all they can to minimise the contribution of the verbal system in visual, and possibly spatial, memory performance. If steps are not taken to do this then results may actually reflect different levels of verbal memory processes rather than visual or spatial memory processes.

CHAPTER 7

General Discussion and Conclusion

7.1 Chapter Introduction

7.2 Overview of the Results

7.3 Limitations

7.4 Implications

7.5 Recommendations for Future Research

7.6 Conclusions

7.1 Chapter Introduction

It is common knowledge that the world's population, particularly in developed nations, is aging (ABS, 2002). This knowledge is supported by figures from Government departments, for example, the Australian Bureau of Statistics, projecting that the percentage of our population over 65 years will continue to increase over the coming decades. The increasing age of the population stresses a need to better understand the aging process, the need to determine those processes that may change or those that remain stable. Cognitive aging researchers have accepted this challenge and already an extant literature exists reporting age-related differences, and similarities, in a variety of cognitive processes including working memory processes.

The current thesis aimed to add to the existing knowledge in working memory functioning across the adult lifespan by examining age-related differences in verbal, visual and spatial working memory. The major questions that were addressed are: Do each of the different types of memory decline with age, and if so, are they affected by age to the same extent? The aim of the current chapter is fivefold: to provide an overview of the results of the three studies conducted to achieve the aims of the thesis, to discuss the limitations of the current thesis, to consider the implications of the results of this thesis, to provide some suggestions for future research, and finally to draw some conclusions from the results of this thesis.

7.2 Overview of the Results

Before the main aims of the current thesis could be achieved it was important to first determine whether people use verbal labels to remember visual and spatial stimuli as has been suggested by previous research (see for example, Bahrick & Boucher, 1968). If verbal labels are being used to remember these stimuli, then we cannot be certain that visual and spatial processes are being assessed as performance is likely to reflect confounding input from the verbal system. Therefore, the first study of this thesis examined the effect of articulatory suppression on verbal, visual and spatial memory performance to determine whether participants used verbal labels to remember visual and spatial stimuli.

Consistent with previous research verbal memory performance was impaired by the inclusion of an articulatory suppression task. Verbal memory was impaired because articulatory suppression uses resources from the articulatory control process of the phonological loop, thereby preventing the items from being subvocally rehearsed. It also prevents visually presented verbal items from being recoded into phonological form, thereby preventing access to the phonological store. More importantly, in the context of the current thesis, visual memory was also impaired by the suppression task. This finding suggests that participants were verbally encoding the visual stimuli. The current study also found impairment in spatial memory with the inclusion of the suppression task, but the impairment was not as severe as it was for visual memory. It is possible that participants used some form of verbal encoding of the spatial locations, for example, top left, bottom right or so on.

The results from Experiment One are particularly important in the context of the current thesis and in the context of visual and spatial memory research in general. These results show that participants do use verbal labels to remember these stimuli and as a result, performance on visual and spatial tasks without means to prevent this recoding process does not reflect visual or spatial processes alone. Performance must partially reflect verbal memory processes as well. Different types of visual and spatial stimuli are likely to draw on varying amounts of verbal processing depending on the ease at which the items can be verbalised. Articulatory suppression provides an effective means to minimise verbal encoding and should be considered in future visual and spatial memory research.

The results of Experiment One clearly demonstrated that participants were using verbal labels to remember visual and spatial stimuli. Articulatory suppression helps prevent the use of verbal labelling strategies. Therefore, one could assume that visual and spatial tasks with the inclusion of an articulatory suppression task would constitute more reliable indicators of visual and spatial memory constructs. Experiment Two aimed to test this hypothesis by examining the reliability and validity of a number of verbal, visual and spatial memory tasks that were used to examine age-related differences in Experiment Three. Each of the tasks, except for letter orientation, was shown to be relatively reliable and valid indicators of verbal, visual or spatial memory. Letter orientation was replaced with a letter location task in Experiment Three that was similar in design to the dot location task and therefore was assumed to tap spatial memory processes.

Based on the results of Experiment Two, it was determined that all of the memory tasks, with the exception of letter orientation, showed adequate evidence of being reliable and valid indicators of verbal, visual or spatial memory. Consequently, these tasks could be used to discriminate between the different constructs in Experiment Three which examined age-related differences in these constructs. The results of Experiment Three revealed that verbal and spatial memory declined with age. However, there was very little difference between young and middle aged adults' performance on these tasks. For visual memory, there was only evidence of decline between middle and old age and this decline was found not to be age-related. There was no difference between young and older adults performance on the visual tasks. The results of Experiment Three also revealed a differential affect of age on verbal, visual and spatial memory performance. Age accounted for more of the variance in spatial memory than in verbal and visual memory even when other factors known to affect cognitive ability across the lifespan were included in the regression models (processing speed, number of medications and central executive functioning). Age did not contributed to visual memory performance at all once these variables were considered. An interesting result from Experiment Three was that the number of medications a person takes a day was more important for performance on the visual tasks than age. However, it is unclear why this is the case and what types of medication, or combination of medications, may be important.

Further analysis of the data for Experiment Three revealed that while there was a significant difference between all of the age groups in processing speed as assessed by reaction times, there was no significant difference in the levels of accuracy between the different groups. In other words, although the middle and the older age groups were slower in responding, their ability to correctly identify the pairs as being the same or different was, in general, the same as the younger adults. Processing speed has been considered a fundamental mediator of age-related variance on a number of cognitive tasks. The results of Experiment Three are consistent with this point of view for verbal and visual memory; however, processing speed did not make a significant contribution to spatial memory performance at all. It appears, therefore, that not only is there a differential effect of age on verbal, visual and spatial memory performance but there is also a differential effect of processing speed.

Another important issue highlighted by the results of Experiment Three related to the role of the central executive on each of the different types of memory. Like age and processing speed, the central executive made differential contributions to each type of memory explaining more of the variance in verbal memory than in visual and spatial memory. Given that the verbal tasks used in this study were clearly working memory tasks in that they required processing and storage abilities, this result is not surprising. Visual and spatial memories were tested using short-term memory tasks that only required remembering a number of shapes or locations. However, central executive functioning explained a significant proportion of the variance in both types of memory. Interestingly, it explained more of the visual memory variance than spatial memory variance, suggesting a closer link between the central executive and visual memory than between the executive and spatial memory. Another interesting result was that the contribution of processing speed to the variance in verbal memory was reduced to non-significance once the central executive variable was included in the analysis. This result suggests that the central executive is more important to verbal memory performance than is processing speed.

On the basis of these results we can conclude that verbal and spatial memories do decline with age, but visual memory does not. We can also conclude that verbal, visual and spatial memories are differentially affected by age. However, interpretation of the results is affected by a number of factors which will now be discussed.

7.3 Limitations

The research conducted for this thesis was cross-sectional research and therefore the results reflect differences between different cohorts rather than actual changes that may occur across the lifespan. There is no way of knowing how the younger and middle aged adults in Experiment Three would perform on these tasks when they reach old age. There is also no possible way of knowing how the older adults would have performed on these tasks when they were middle aged or young adults. There is a need for more longitudinal research designs to track changes in individuals across the lifespan before these issues can be determined. However, cross-sectional studies have the advantage of providing means to develop hypotheses about cognitive aging which can then be tested in future longitudinal studies.

Another limitation of the current thesis was that the middle age group comprised mainly participants who were either in full time study or who were in positions that demand a high level of education. As a consequence, the peak in performance in middle age on the verbal and visual tasks, and the lack of difference between young adulthood and middle age on the spatial tasks, may have been a function of continued cognitive activity rather than a reflection of what occurs in all middle aged adults. Future research using a more diverse range of middle aged adults will help clarify this matter.

Recruitment of research participants is a difficult process. Often one needs to rely on university undergraduates or highly motivated volunteers from the general community. Such methods of recruitment reduces the generalisability of the results, however, they do allow us to gather important information that can be further examined in future research using different samples. Further, people from the general community who volunteer to participate in research projects tend to have higher than average levels of cognitive ability. It is important that cognitive aging researchers find ways to encourage older adults across a range of cognitive abilities to participate in research projects. Only then can we fully understand how these processes are truly affected by age. Moreover, if we can determine differences in performance between those who maintain high levels of cognitive ability to those who show decreased ability, in the absence of dementia, it may be possible to find ways to help people maintain, or even improve cognitive performances. It may be possible to increase participation by presenting a series of public information sessions designed to explain the benefits of the project to an aging population.

Performance levels on the visual tasks suggest that people of all ages have difficulty processing the stimuli used in these tasks. One reason for this is that the items are not items that one would expect to encounter in the real world therefore they would be more difficult to remember than digits, words, letters, and locations that are encountered on a daily basis. What is needed when assessing visual memory are stimuli that are more like those encountered in the real world. The difficulty here, of course, is finding ways to present the items so that one is testing visual memory and not verbal memory. This is likely to be a difficult task but it is one that needs to be tackled before we can truly understand what is happening with visual memory as a function of increased age.

A further limitation of the current thesis is that it only tested explicit memory processes not implicit memory. There is evidence to suggest that implicit memory does not decline across the adult lifespan (Hoyer & Verhaeghen, 2006). In tests of explicit memory participants are aware that they need to remember the items for later recall or recognition, whereas in tests of implicit memory participants are not aware of this requirement. This point leads one to wonder whether participants would automatically attach verbal labels to stimuli in visual and spatial implicit memory tasks. If verbal labelling is an automatic process one would expect that they would. However, if participants are unaware of the need to remember the stimuli then this may not be the case. It would be interesting to examine the effects of articulatory suppression on performance on implicit memory tests to determine whether or not verbal labelling is truly an automatic process.

Despite the limitations of the current thesis, the results of the studies conducted to achieve its aims add to our understanding of working memory and how it is affected by increased age. The following section covers a number of important issues raised by the results of this thesis.

7.4 Implications

The results of the current thesis not only increase our understanding of the relationship between age and visual and spatial memory, they also raise some very important issues that need to be addressed in future research on cognitive aging, particularly in relation to working memory processes. First, the results from Experiment One highlight the need to ensure that visual and spatial memory performance is not confounded by contributions from the verbal system. It is possible to minimise verbal labelling of visual and spatial stimuli by including an articulatory suppression task during the encoding stage of these tasks.

The results of Experiment Two show that verbal, visual and spatial memory can be assessed as separate representations using the types of tasks used in this thesis. This finding is consistent with the multicomponent nature of the working memory model first proposed by Baddeley and Hitch (1974). It is also consistent with the notion that working memory comprises domain-specific systems each responsible for processing different types of information (Baddeley, 2001). It is important that each of these different types of memory are assessed independently, particularly in cognitive aging research, because as shown in Experiment Three, they are not affected by increased age to the same extent.

Another important implication of the current thesis is that it draws our attention to the need to compare performance across a range of ages from young adulthood through to old age, including a middle age group. Performance on a number of cognitive tasks may reach a peak during middle age and, as was shown in Experiment Three, while there was no difference between young and older adults' visual memory performance, there was a difference between the middle and the older age groups. Although this difference does not appear to be age-related, it may be the case that, for some cognitive tasks, decline does not become apparent until after middle age. If we do not include a middle age group in our studies we are not likely to obtain a true picture of the aging process.

The view of general slowing with increased age appears to be correct in that reaction times on the processing speed tasks steadily increased across the different age groups. It is important therefore, that older adults are given the time they need to complete the tasks. They should not feel under pressure to respond within a certain period of time as this will likely affect their performance. Finally, the results of the current thesis highlight the need to consider the role of the central executive in performance on working memory tasks because the link between visual working memory processes and the central executive may be closer than the link between spatial working memory processes and the central executive.

One of the major implications of the current thesis is that it supports the distinction between verbal, visual and spatial memory as predicted by the working memory model in its current form. It is crucial that we examine each of these three different types of memory independently. Why? Because, as has been shown by the results of this thesis, different factors likely affect the different types of memory in different ways.

7.5 Recommendations for Future Research

The results of this thesis have raised a number of questions that need to be addressed in future research, some of which have already been discussed. For example, future research needs to examine more closely what is happening to verbal, visual and spatial working memory processes in middle age using a more diverse group than the one used here. The relationship between medication and visual memory performance needs to be examined to look more closely at the types of medication people take to determine which types may be affecting visual memory performance and why they are affecting visual memory performance. More research examining the relationship between the central executive and the visual component of the working memory model is also needed. If these two components are as closely linked as the current research seems to suggest, then is visual memory really a distinct component of the working memory model or just a part of the central executive?

Testing these types of memory in the laboratory is a necessary process because it allows us to tease apart each of the different types of memory and examine what is happening to them as a function of increased age. However, once this has been achieved, we then need to examine how these results relate to everyday life. What does a lack of age-related decline in visual memory mean for older adults in their everyday life? Are there ways we can use this knowledge to help people use visual strategies to compensate for losses in the other types of memory?

Another avenue for future research needs to be an examination of what these results mean in terms of everyday functioning for older adults. It is likely that in daily life many of the tasks undertaken by older adults are tasks they undertake on a daily basis and therefore they do not require effortful processing (Park & Hall Gutchess, 2000). Finding the way to the shopping centre (spatial memory), for example, would be a familiar activity that requires little conscious effort. However, consider an elderly person living in a country town having to travel to the city, for the first time, to receive medical treatment. The area would not be familiar and therefore the process would be a difficult one that would require a great deal of mental effort on the part of the older adult. This may be particularly important if the person is driving a car in an unfamiliar area. Another area of concern relates to remembering medical treatment instructions. Given that verbal working memory declines with age many older adults are unlikely to remember what a doctor has told them they need to do once they get home. The results of the current thesis show that visual memory remains relatively unaffected by increased age. Could we use this knowledge to develop strategies to help older adults better remember doctors’ instructions? It is extremely important that we increase our knowledge of cognitive functioning across the lifespan. It is also as important that we use this knowledge to increase understanding of how these factors affect older adults’ daily lives.

Finally, the reliability and validity of the tasks used in this thesis need to be replicated in different samples to ensure that the tasks are indeed reliable and valid indicators of the different types of memory. It would also be beneficial to include an examination of the factor structure of the tasks in different age groups as it is likely that the distinct verbal, visual and spatial components of working memory become less distinct in older age.

7.6 Conclusions

Baddeley and Hitch's (1974) original model of working memory was a multicomponent model that comprised a domain-general attentional controller referred to as the central executive and two domain-specific slaves systems, the phonological loop and the visuo-spatial sketchpad. The phonological loop is responsible processing verbal information while the sketchpad is responsible for processing visual and spatial information. The domain-specificity of the slave systems highlights the fact that working memory comprises a number of distinct types of memory. Particularly important for the current thesis are verbal, visual and spatial memories.

There are very few studies that have directly compared age-related differences in verbal, visual and spatial memory performance. The main aim of the current thesis was to determine whether verbal, visual and spatial memory declined with age and if so, whether that decline was equivalent or different across the different types of memory. On the basis of the results of this thesis we can conclude that verbal and spatial memory show evidence of decline in old age but there is very little difference between young and middle age. Visual memory only shows decline after middle age. However this decline appears to be related to the number of medications a person takes a day, the speed at which they process information and central executive functioning rather than to increased age. Verbal, visual and spatial memories are not affected by age to the same extent. Age explains more of the variance in spatial memory than in verbal and visual memory regardless of whether other variables known to influence cognitive functioning are included in the analysis or not.

The speed at which a person can process information has been suggested to be an important mediator of age-related variance on working memory tasks, particularly verbal working memory tasks. While the results of the current thesis are consistent with this view, they provide evidence that the relationship between processing speed and verbal, visual and spatial memory performance is not the same. Processing speed was shown to mediate the variance in verbal and visual memory but not in spatial memory. The same applies to the role of the central executive in performance on each of the different types of memory – it is not the same. Central executive functioning appears to be important for verbal and visual memory performance, but it is not as important for spatial memory performance.

The results of the current thesis not only increase our understanding of the relationship between age and verbal, visual and spatial memory, they also highlight a number of important methodological issues that cognitive aging researchers need to consider in future research. The review of the visual and spatial memory and aging literature highlighted a lack of consistency as to whether each of these types of memory declined with age or not. Some researchers report declines and others report stability. Part of the difficulty in obtaining a clear picture of the nature of the affects of age on visual memory processes lies in the way it has been examined in previous research. Visual memory is more often assessed using recognition tasks while verbal and spatial memory are assessed using recall tasks. Comparisons are then made between the different types of memory, for example between visual and verbal memory. Any resulting apparent differences may reflect differences in performing recall tasks as compared to recognition tasks rather than differences in visual and verbal memory. It really is also not clear whether the processes tested in previous research are in fact visual or spatial memory processes because there has been relatively little concern for the concept that people have a natural and pervasive tendency to attach verbal labels to visual, and possibly spatial, stimuli. Consequently, previous research may have been testing varying levels of verbal memory processes rather than solely visual or spatial memory processes. Designing visual and spatial stimuli that are found to be difficult to label verbally does not exclude the possibility that people will still try to attach labels to the stimuli to aid memory for the items. Researchers can go a long way to minimising the contribution of the verbal system to visual and spatial memory performance by including an articulatory suppression task during the encoding stage of the task. While articulatory suppression will not completely prevent verbal labelling, it will certainly minimise it and therefore make us more confident that we are testing visual memory processes. As a result, we may be able to draw a clearer picture of the nature of age-related effects on visual and spatial memory process.

Working memory is a multicomponent system with distinct verbal, visual and spatial components. Each of these components is differentially affected by age. It is unclear why this is the case. However, it is possible that the lack of age-related decline in visual memory in the current thesis reflects that fact that participants were prevented from using verbal labels to remember these stimuli. As a result, participants in each of the age groups were forced to depend more heavily on visual codes. Because people have developed a natural tendency to attach verbal labels to visual stimuli they are less practiced at using visual codes as evidenced by the poor performance of each of the age groups on the visual tasks. This preference to use verbal labels appears to extend across the lifespan strengthening the view that age-related differences in visual memory reported in previous research may actually reflect differences in verbal memory.

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Appendix

Demographic and Health Status Questionnaire

Participant Identification Number: ……..

Age (In years at time of study): ……..

Gender: Male / Female

Level of Education (In years): …….

Number of medications per day: …….

Health Status

Please Circle

1. Have you ever had a stroke or transient ischemic attack? Yes / No
2. Have you been seen by a neurologist or neurosurgeon? Yes / No
    a. (If yes) Was this for a back or neck problem? Yes / No
    b. (If yes) Was this for a tension headache? Yes / No
3. Have you had cancer, other than skin cancer, diagnosed within the last three years? Yes / No
4. Do you have shortness of breath while standing still? Yes / No
5. Do you use home oxygen? Yes / No
6. Do you have difficulty understanding conversations because of your hearing even if you are wearing a hearing aid? Yes / No
7. Do you have trouble with your vision that prevents you from reading ordinary print even when you have glasses on? Yes / No
8. Have you had heart surgery? Yes / No
9. Have you ever been resuscitated? Yes / No

10. Do you drink beer, wine, or other alcoholic beverages every day or less often? Daily/Less
    a. (If daily) How many drinks do you have each day? ……….
11. Have you ever had a problem due to abuse of drugs or medication? Yes / No
    a. (If yes) Was this within the past five years? Yes / No
12. Have you ever been treated for alcohol or drug abuse? Yes / No
    a. (If yes) Was this within the past five years? Yes / No
13. Do you have diabetes that requires insulin control? Yes / No
14. Do you have hypertension that is not well controlled? Yes / No
15. Have you had a head injury with loss of consciousness greater than 5 minutes? Yes / No
16. Have you ever been unconscious for more than 1 hour other than during surgery? Yes / No
17. Have you ever required hospitalisation because of a head injury? Yes / No
18. Have you had encephalitis or meningitis? Yes / No
19. Have you ever had a heart attack? Yes / No
    a. (If yes) Did you have any change in your memory, ability to talk or solve problems 24 hours after your heart attack? Yes / No
20. Are you currently taking medication for mental or emotional problems? Yes / No
21. Have you been hospitalised for mental or emotional problems in the past five years? Yes / No

22. Have you ever had seizures? Yes / No
23. Do you have Parkinson’s disease? Yes / No
24. Have you ever had brain surgery? Yes / No
25. Have you ever undergone surgery to clear the arteries of the brain? Yes / No
26. Have you ever had any illness that caused a permanent decrease in memory or other mental functions? Yes / No
27. Have you ever received electroshock therapy? Yes / No
28. Have you ever been diagnosed as learning disabled? Yes / No
29. Were you placed in special classes in school because of learning problems? Yes / No
30. Have you been diagnosed as having a brain tumour? Yes / No
31. Do you have difficulty using your hands? Yes / No
32. Have you ever had major surgery with general anaesthesia? Yes / No
    a. (If yes) Did you have any change in memory, ability to talk or solve problems one week after surgery? Yes / No
33. Do you have multiple sclerosis, cerebral palsy, or Huntington’s disease? Yes / No
34. Are you receiving kidney dialysis? Yes / No
35. Do you have a liver disease? Yes / No
36. Do you have lupus? Yes / No

(from Christensen et al., 1992).