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Differential Visual Short Term Memory Performance Between Young and Healthy Older Adults

Mark James Horne

Thesis presented for the degree of
Doctor of Philosophy

University of Edinburgh
2015
Dedicated to Mum, Dad, Nan, Grandad, Emma, and Charlie.
Declaration

I declare that this thesis is my own composition, and that the material contained in it describes my own work. It has not been submitted for any other degree or professional qualification. All quotations have been distinguished by quotations marks and all sources of information have been acknowledged.

Mark James Horne

27th February 2015
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Thank you to all who helped and guided me whilst writing this thesis.

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Thank you to Charlie for reading through so many draft copies of various pieces of work.

Finally, I would like to say thank you to my family for helping me through the incredibly long journey my university education proved to be. It wouldn’t have been possible without you.

This is, the word, that year by year,
While in her place, the school is set,
Every one of her sons must hear,
And none, that hears it dare forget.
This, they all with a joyful mind
Bear, through life like a torch in flame,
And, falling, fling, to, the host behind—
"Play up! Play up! And play, the game!"

Vitaï Lampada
Sir Henry John Newbolt.
## Contents

Abstract ................................................................................................................................. 7  
List of Figures ...................................................................................................................... 9  
List of Tables ...................................................................................................................... 10  
Chapter 1 ............................................................................................................................ 12  
  Introduction ...................................................................................................................... 12  
  Working Memory: Definitions and concepts ................................................................. 16  
  Cognitive Ageing: Methods and theories ....................................................................... 36  
  Variation in Working Memory Performance .................................................................. 48  
  Age-Related variation in Working Memory Performance ............................................. 60  
  Development of Rationale ............................................................................................. 71  
Chapter 2 ............................................................................................................................ 76  
  Experiment 1 .................................................................................................................. 76  
    Methods ...................................................................................................................... 81  
    Results ......................................................................................................................... 83  
    Discussion ................................................................................................................... 86  
  Experiment 2 .................................................................................................................. 89  
    Methods ...................................................................................................................... 91  
    Results ......................................................................................................................... 96  
    Discussion ................................................................................................................... 100  
  Experiment 3 .................................................................................................................. 104  
    Methods ...................................................................................................................... 107  
    Results ......................................................................................................................... 110  
    Discussion ................................................................................................................... 112  
  A recap of Chapter 2 ...................................................................................................... 115  
Chapter 3 ............................................................................................................................ 119  
  Experiment 4 .................................................................................................................. 126  
    Methods ...................................................................................................................... 128  
    Results ......................................................................................................................... 131
<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>Discussion</td>
<td>133</td>
</tr>
<tr>
<td>Experiment 5</td>
<td>135</td>
</tr>
<tr>
<td>Methods</td>
<td>136</td>
</tr>
<tr>
<td>Results</td>
<td>137</td>
</tr>
<tr>
<td>Discussion</td>
<td>138</td>
</tr>
<tr>
<td>Chapter 4</td>
<td>148</td>
</tr>
<tr>
<td>Experiment 6</td>
<td>148</td>
</tr>
<tr>
<td>Methods</td>
<td>157</td>
</tr>
<tr>
<td>Results</td>
<td>158</td>
</tr>
<tr>
<td>Discussion</td>
<td>162</td>
</tr>
<tr>
<td>Experiment 7</td>
<td>164</td>
</tr>
<tr>
<td>Methods</td>
<td>165</td>
</tr>
<tr>
<td>Results</td>
<td>166</td>
</tr>
<tr>
<td>Discussion</td>
<td>168</td>
</tr>
<tr>
<td>A Recap of Experiments 6 &amp; 7</td>
<td>171</td>
</tr>
<tr>
<td>Experiment 8</td>
<td>175</td>
</tr>
<tr>
<td>Methods</td>
<td>178</td>
</tr>
<tr>
<td>Results</td>
<td>181</td>
</tr>
<tr>
<td>Discussion</td>
<td>184</td>
</tr>
<tr>
<td>Chapter 5</td>
<td>190</td>
</tr>
<tr>
<td>Summaries</td>
<td>190</td>
</tr>
<tr>
<td>Differential effects of Articulatory Suppression</td>
<td>190</td>
</tr>
<tr>
<td>Cross-Modal task performance in the Visual Patterns Task</td>
<td>194</td>
</tr>
<tr>
<td>Cross-Condition performance in the Visual Patterns Task</td>
<td>197</td>
</tr>
<tr>
<td>Executive recruitment in visual tasks</td>
<td>199</td>
</tr>
<tr>
<td>A Brief Recapitulation</td>
<td>200</td>
</tr>
<tr>
<td>Conclusions</td>
<td>201</td>
</tr>
<tr>
<td>References</td>
<td>208</td>
</tr>
<tr>
<td>Appendices</td>
<td>231</td>
</tr>
<tr>
<td>Appendix A</td>
<td>231</td>
</tr>
<tr>
<td>Appendix B</td>
<td>233</td>
</tr>
</tbody>
</table>
Abstract

The research reported was inspired by the Perfect and Maylor (2000) chapter ‘Rejecting the Dull Hypothesis’. This suggested that cognitive ageing research should not focus purely on whether younger adults outperform older adults on a given task. Hartley, Speer, Jonides, Reuter-Lorez and Smith (2001) showed that older adults do not maintain the dissociability of naming identity, visual identity, and spatial location abilities that is seen in younger adults. Away from the ageing literature, Brown, Forbes and McConnell (2006) demonstrated improvement in visual task performance when the availability of verbal coding was increased. The hypothesis that older adults are less likely to use task specific cognitive mechanisms during short-term visual memory tasks was explored. This was carried out by means of a series of 8 experiments (outlined below), which broadly looked at differences in verbal interference effects on visual task performance, differences in Visual Patterns Task performance based on the availability of verbal encoding, and assessed for age-related differences in interference from an executive task in Visual Patterns Task performance. Data was interpreted through the prism of the Scaffolding Theory of Aging (Park & Reuter-Lorenz, 2009), which suggests that compensatory recruitment is employed both young and older adults in response to extrinsic challenges such as task difficulty, and intrinsic challenges, such as declining performance with age.

Experiments 1-3 focused on differential effects of articulatory suppression on visual task performance between young (18-25) and older (60-75) adults. Older adults showed negative effects of suppression in short-term maintenance tasks that were not present in younger adults. Both age groups showed negative effects in a mental image rotation task. This suggested a level of verbal activation in visual tasks for both age groups, but that this activation was more common in older adults.

Experiments 4-5 assessed differences in Visual Patterns Task performance between both age-groups depending on the availability of verbal encoding. Younger adults displayed the benefit of available verbal encoding with simultaneous but not sequential...
presentation of information. Older adults showed a benefit of verbal coding in the simultaneous task if the sequential task featured ordered, not randomised presentation pathways. This suggested that older adult task performance may be affected by all conditions within an experiment, not just the current manipulation condition.

Experiments 6-7 demonstrated that older adults’ performance in the simultaneous presentation version of the Visual Patterns Task is affected by the availability of verbal encoding in the first task presented to them. Mean performance on subsequent conditions was higher when ‘high verbal coding’ patterns were seen in the first instance. This was not the case for younger adults. The demonstration of a benefit to performance from the ‘high-verbal coding’ pattern set compared to the ‘low-verbal coding’ set was a marker of higher overall performance across all task conditions for younger adults, but not for the older group. This suggested that even if verbal activation during visual task performance was an occurrence for older adults, it was not necessarily a marker for improved performance.

Experiment 8 demonstrated that there were no age-related differences in the level of interference from an executive task (Random Month Generation) on Visual Patterns Task performance. This suggested that older adults do not try to actively recruit executive processes during Visual Patterns Task performance to any greater extent than younger adults do.

It is suggested that older adults do use specialised task mechanisms to a lesser extent than younger adults in visual memory task performance. It is likely that this is a passive outcome of a decreased inhibition of verbal coding mechanisms, rather than an active attempt to maintain performance through the recruitment of executive cognitive resources. This is seen by the lack of age-group effects from executive interference tasks.
# List of Figures

<table>
<thead>
<tr>
<th>Figure</th>
<th>Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.1</td>
<td>The Logie (2011) model of working memory</td>
<td>26</td>
</tr>
<tr>
<td>1.2</td>
<td>The Cowan (2005) Embedded Processes Model of working memory</td>
<td>29</td>
</tr>
<tr>
<td>1.3</td>
<td>The Engle et al. (1999) model of working memory</td>
<td>33</td>
</tr>
<tr>
<td>2.1</td>
<td>Experimental stimuli from Brandimonte et al. (1992)</td>
<td>82</td>
</tr>
<tr>
<td>2.2</td>
<td>Mean pattern set scores by interference task condition on the Brandimonte et al. stimuli</td>
<td>86</td>
</tr>
<tr>
<td>2.3</td>
<td>Process of the spatial memory task used in Experiment 2</td>
<td>95</td>
</tr>
<tr>
<td>2.4</td>
<td>Mean visual and verbal task scores by interference condition in Experiment 2</td>
<td>97</td>
</tr>
<tr>
<td>2.5</td>
<td>Mean utterance/tapping rates in interference tasks when maintaining information from verbal memory task</td>
<td>99</td>
</tr>
<tr>
<td>2.6</td>
<td>Mean utterance/tapping rates in interference tasks when maintaining information from visuo-spatial memory task</td>
<td>100</td>
</tr>
<tr>
<td>2.7</td>
<td>Mean simultaneous and sequential memory task scores by interference condition in Experiment 3</td>
<td>111</td>
</tr>
<tr>
<td>2.8</td>
<td>Relative dual task score as a percentage of single task performance in Experiment 3</td>
<td>112</td>
</tr>
<tr>
<td>3.1</td>
<td>Mean VPT scores in ETN/HTN Patterns with simultaneous and sequential-ordered presentation in Experiment 4</td>
<td>131</td>
</tr>
<tr>
<td>3.2</td>
<td>Mean VPT scores in ETN/HTN Patterns with simultaneous and sequential-Randomised presentation in Experiment 5</td>
<td>137</td>
</tr>
<tr>
<td>4.1</td>
<td>Presentation order effects on neutral scores with simultaneous presentation in Experiment 6</td>
<td>160</td>
</tr>
<tr>
<td>4.2</td>
<td>Mean scores on ETN/HTN pattern sets for both age groups with ETN or HTN patterns presented first (Simultaneous).</td>
<td>161</td>
</tr>
</tbody>
</table>
Figure 4.3  Presentation order effects on neutral scores with sequential-ordered presentation ............................................. 166

Figure 4.4  Mean scores on ETN/HTN pattern sets for both age groups with ETN or HTN patterns presented first (Sequential)……… 167

Figure 4.5  Mean percentage correct in VPT across span conditions and interference tasks......................................................... 182

List of Tables

Table 4.1  Mean scores on neutral pattern scores for both age groups split into sub-groups based the on presence of nameability effect in ETN/HTN pattern sets. (Simultaneous)................................................................. 162

Table 4.2  Mean scores on neutral pattern scores for both age groups split into sub-groups based the on presence of nameability effect in ETN/HTN sequential-ordered pattern sets. (Sequential)................................................................. 168

Table 4.3  Mean AS utterance rates for Young and Older adults in at-span and below-span conditions during 10 second maintenance period ................................................................. 182

Table 4.4  Mean RMG utterance rates for Young and Older adults in at-span and below-span conditions during 10 second maintenance period................................................................. 182

Table 4.5  Mean RMG scores for Young and Older adults in at-span and below-span conditions during 10 second maintenance period… 184
List of Abbreviations

*In alphabetical order*

<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>ANOVA</td>
<td>Analysis of Variance</td>
</tr>
<tr>
<td>AS</td>
<td>Articulatory Suppression</td>
</tr>
<tr>
<td>EPM</td>
<td>Embedded Processes Model</td>
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<tr>
<td>ETN</td>
<td>Easy-to-Name</td>
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<tr>
<td>fMRI</td>
<td>functional Magnetic Resonance Imaging</td>
</tr>
<tr>
<td>HTN</td>
<td>Hard-to-Name</td>
</tr>
<tr>
<td>LTM</td>
<td>Long term Memory</td>
</tr>
<tr>
<td>MCM</td>
<td>Multiple Component Model</td>
</tr>
<tr>
<td>MMSE</td>
<td>Mini Mental State Exam</td>
</tr>
<tr>
<td>PET</td>
<td>Positron Emission Tomography</td>
</tr>
<tr>
<td>PM</td>
<td>Primary Memory</td>
</tr>
<tr>
<td>RMG</td>
<td>Random Month Generation</td>
</tr>
<tr>
<td>RNG</td>
<td>Random Number Generation</td>
</tr>
<tr>
<td>SM</td>
<td>Secondary Memory</td>
</tr>
<tr>
<td>STAC</td>
<td>Scaffolding Theory of Aging and Cognition</td>
</tr>
<tr>
<td>STM</td>
<td>Short term Memory</td>
</tr>
<tr>
<td>VPT</td>
<td>Visual Patterns Task</td>
</tr>
<tr>
<td>VSSP</td>
<td>Visuo-spatial Sketch Pad</td>
</tr>
<tr>
<td>WM</td>
<td>Working Memory</td>
</tr>
</tbody>
</table>
Chapter 1

Introduction

The classic experimental psychological paradigm typically involves the use of null hypothesis significance testing in order to ascertain whether the manipulation of an independent variable has an effect on a dependent variable. Commonly these effects are compared between groups, or on one group at two time points, with the aim being to identify differences in the accuracy or levels of performance. Whilst there are obvious benefits to a method that seeks to objectively identify differences in cognitive performance, there is an argument to suggest that simply testing for overall performance differences or declines does not lend itself to fruitful research in the field of cognitive ageing.

Studies of cognitive ageing commonly find declines in overall cognitive performance across the lifespan (Deary et al., 2007; Lindenberger, Mayr & Kliegl, 1993). However, simply identifying a general decline in task scores is not enough to explain how or why some tasks decline at a faster rate than others. Perfect and Maylor (2000) suggested that simply searching for overall decline in cognitive tasks with increasing age represents a ‘dull hypothesis’. It was their assertion that the classic null hypothesis research paradigm outlined above was of little benefit to ageing research.

Indeed to simply state that older adults demonstrate poorer cognitive performance than younger adults is akin to reporting a slowing of sprinting times, or shortening of distances thrown between two age-groups at an athletics event. Greater information regarding the cognitive changes and decline that older adults experience is to be gained from studies assessing abilities that do not decline, or the strategies used by older adults to maintain levels of performance in comparison to younger counterparts. To return to a sporting analogy; in a comparison of swimming performance an older adult who has decreased overall muscle mass compared to a younger adult may have perfected and refined their swimming style over a 30 year period, and as such may be able to mask the physical decline in ability and demonstrate performance similar to that of a younger adult. The overall measure of swimming performance may appear
similar, but the underlying mechanisms by which it was achieved may be different. Perfect and Maylor suggested that we should not focus on merely demonstrating that younger adults outperform older adults and we should instead reject this ‘dull hypothesis’ (Perfect & Maylor, 2000, p2). By attempting to understand the manner in which people achieve their levels of cognitive performance, rather than simply measuring an outcome, such as a mean score or common variance across a battery of tasks we will gain a much deeper understanding of the processes within cognitive ageing.

Since the publication of ‘Rejecting the Dull Hypothesis’ the concept of differential declines within ageing has been echoed in several other publications, and a brief overview will be provided here. Theoretical frameworks and research output will be discussed in greater detail later in this chapter. Salthouse (1996, 1998, 2000) has argued that monolithic interpretations of ageing are too simplistic and do not represent the complex patterns of decline that are seen in healthy adult ageing. Experimentally this has been shown by Park, Lautenschlager, Hedden, Davidson, Smith, and Smith (2002) who, using a sample of 345 participants demonstrated a decline in process intensive tasks related to speed of processing and working memory that began in participants’ 20s. This was counterbalanced by an increase in verbal knowledge across the lifespan. Johnson, Logie, & Brockmole (2010) also demonstrated differential decline in task performance with age in a large-scale study of 95,000 individuals who had undertaken memory studies on the British Broadcasting Corporation’s (BBC) website. Johnson et al. identified changes in the level of decline and residual variance of 5 short-term and working memory tasks across the lifespan in adults aged 18-90. Visual short-term memory ability declined at a far greater rate than verbal short-term memory ability. It was also found that older adults relied on more general abilities to complete visual tasks, whilst continuing to demonstrate specific abilities in verbal tasks. This suggested that the manner in which optimal task performance is achieved changes with not only age, but with the type of task being undertaken.

Park and Reuter-Lorenz (2009) have suggested the Scaffolding Theory of Aging and Cognition (STAC), in which older adults supplement their performance on tasks through the recruitment of compensatory neural pathways. Two key tenets of this
theory are that, firstly, reactions to intrinsic difficulties, such as the cognitive decline seen in ageing, are similar to reactions to extrinsic difficulties, such as increasing task difficulty. Therefore an older adult may supplement task performance with compensatory recruitment in order to maintain their overall task outcome, whereas a younger adult may turn to compensatory recruitment when faced with a task that begins to reach the limits of their cognitive performance. Secondly, that whilst compensation may aid performance in a given task, in the face of a neural decline it would be unlikely to increase beyond the individual’s original levels of performance. In particular Park and Reuter-Lorenz highlight the visual-ventral cortex as an area which benefits from complementary recruitment of the pre-frontal cortex in older adults. This translates into compensation, but not improvement in visual memory task performance in older adults (Reuter-Lorenz, Stanczak, & Miller, 1999).

An acceptance that understanding task performance in healthy adult ageing is about more than overall performance measures can be of benefit when trying to identify unhealthy cognitive ageing. In a series of studies looking at dual-tasking abilities in healthy young, and older adults, as well as Alzheimer’s patients it has been demonstrated that once individual ability has been controlled for, and tasks are selected to rely on the different cognitive functions, there is no dual-tasking decrement in healthy ageing compared to younger adults. However, the ability to perform two tasks at once appears to be compromised in Alzheimer’s patients (e.g. Foley, Kaschel, Logie, & Della Sala, 2011; Logie, Della Sala, Cocchini, & Baddeley, 2004).

The concept of the ‘dull hypothesis’, as well as the studies briefly described above do not attempt to present an account of older adults performing tasks using some form of general resource as a blanket answer to decline in cognitive ageing. The differentiated declines in task performance seen in cognitive ageing (Park et al., 2002; Johnson et al., 2010) would be an obvious rebuttal to any statement which suggests that there is a single underlying cause of age-related cognitive decline. The concept simply suggests that, either through choice or automatic process, the methods employed in order to complete cognitive tasks are not constant across the lifespan. These can have beneficial or possibly detrimental effects on whichever outcome measure is being used. It is possible that in some cases compensatory recruitment, such as verbally coding the
movement of a spatial sequence might be an optimal method; however, attempting to recall facts presented orally using a method of spatial location may not have a benefit on task performance. The stance of the Perfect and Maylor (2000) chapter, and the stance taken in this thesis does not posit that research into cognitive ageing should be ordered into a dichotomy of work that is ‘for’ or ‘against’ the rejection of the ‘dull’. In fact, work that highlights a decline between young and older adults on given tasks, but can also highlight a change in the relation between tasks is central to understanding how and why cognitive performance changes with age.

A commonly cited longitudinal study presents this argument in a microcosm; Wilson et al. (2002) studied 694 healthy adult males and assessed changes in cognitive ability over the course of 6 years. Decline was found to be greater in those who were older at the beginning of the study, and there was a general decline across all tasks (including story retention, word retention, digit span, perceptual speed, visuospatial ability, and word knowledge). This represents the ‘dull’ hypothesis. However, the authors noted that initial test performance was not a strong predictor of the subsequent rate of decline and there were large individual differences in the rates of decline within differing tasks. Whilst initially appearing to represent a global decline, performance on these tasks could also be characterised as specific to individuals and the methods employed to perform the tasks. Throughout the literature relating to cognitive decline, it is commonly found that there are age-related declines in areas such as short-term memory, Gf (Fluid intelligence) and item recall. Other areas such as Gc (Crystallised intelligence), and measures of verbal fluency are affected to a much lower degree, if at all (Horn & Masunaga, 2000). However, even within categorisations such as this there are differences in performance. Both Park et al. (2002), and Logie and Maylor (2009) have demonstrated differential decline within short-term and working memory tasks with age. Taken alone these findings could be said to be a rejection of the dull hypothesis. These data after all, suggest that there are differential trajectories of declines in different measures of working memory as age increases. However, by also taking into account the changes in task specific variance highlighted by Johnson et al. (2010), the data suggests that not only do different tasks decline at different rates but that by looking beyond overall performance scores we can begin to ascertain the different methods by which tasks are being performed. It is possible that tasks which
are taken to measure performance in one domain are in fact measuring performance across multiple cognitive domains, or indeed measuring an ability to relate the current task to previous knowledge.

This chapter will consider the concept of domain-specific performance within short term and working memory tasks, as well as attempting to provide a brief overview of the types of methodologies employed in cognitive ageing research. It will then go on to outline the research aims and key ideas that are to be carried through to the experimental section of this thesis. In keeping with the suggestions of Perfect and Maylor (2000) it will attempt not only to identify the differences in cognitive performance with age, but the manner in which these differences manifest themselves. The concept of cognition is of course, exceptionally broad, taking in concepts such as general intelligence, attention, and memory performance. As such, this thesis shall focus on working memory, and in particular the visual domain. This is due to a number of factors, which shall be explored fully later in this review; however the findings of Logie and Maylor (2009), and Park et al. (2002) which have demonstrated the differential decline in visual and verbal task abilities with ageing provide an ample starting point. The next two sections of this work will concern themselves with an overview of the working memory literature, and an overview of literature concerning cognitive ageing.

**Working Memory: Definitions and concepts**

Working memory is defined as a system of temporary memory and mental processing (e.g. Baddeley, 2007; Cowan, 2005; Logie, 2011). It encompasses the encoding, storage, and maintenance of new information, as well as differences in capacity for attending to, and remembering new information between individuals. It is the inclusion of processing and manipulation of information as well as temporary storage that differentiates the broader concept of working memory from short-term memory, with the latter being a component of the former. The functions of working memory are common to all healthy adults, and there is a large body of developmental research
(Pickering, Gathercole, Hall, & Lloyd, 2001; Towse, Hitch, & Hutton, 1998, 2000), as well as a large body of ageing research (Brockmole & Logie, 2013; Brown, Brockmole, Gow, & Deary, 2012; Lecerf & De Ribaupierre, 2005) describing the performance of working memory across the lifespan. The majority of research focusing on working memory is laboratory based behavioural research, however, the easy to administer nature of commonly used memory tasks such as digit span and ‘N-Back’ have led to a large field of imaging research attempting to outline the cognitive neuroscience of working memory (For reviews see Osaka, Logie, D’Esposito, 2007; for a critique see Page, 2006). Research into working memory has led to many practical applications. Indeed, the impairment of working memory processes that appear to be well maintained in healthy older adults, such as the ability to perform two cognitive tasks have been identified as properties and indicators of Alzheimer’s Disease (Logie et al., 2004; MacPherson, Parra, Moreno, Lopera & Della Sala, 2012).

As would be expected from such a broad field of research, there are numerous theoretical models of working memory. Each of these has spawned their own bodies of research and each has their own emphases, although these differences in emphasis are broadly based on research questions, rather than theoretical differences (Logie, 2011). The focus of this thesis, as already outlined, will be the changes in visual short term and working memory performance in older adults. Performance on a visual task may represent a small part of what is constituted as working memory, but it will serve the purposes of this work to provide an overview of some of the key theoretical models and concepts in working memory research. We shall, in turn assess the Multiple Component Model (Baddeley & Hitch, 1974; Baddeley, 1986; Baddeley, 2007; Logie, 2011), the Embedded Processes Model (Cowan, 1988, 2005), and the concept of Primary and Secondary Memory (Unsworth & Engle, 2006). Having provided a broad explanation of their assumptions we will assess the areas in which these models complement each other, and those in which they do not. It will then be considered how to place these ideas in the context of this research.
The Multiple Component Model

The Multiple Component Model (MCM) was first outlined by Baddeley and Hitch in 1974, and developed by Baddeley (1983; 1986). The tripartite system first reported in Baddeley (1983) was presented as a development of Atkinson and Shiffrin’s (1968) Modal Model, which in itself was a product of the unitary vs separate memory debate of the 1960s (Keppel & Underwood, 1962), and of the proposals from Broadbent (1958) regarding a short-term memory acting as an attentional filter and temporary store, separate from long-term memory. Atkinson and Shiffrin’s modal model was an early attempt to provide a theoretical framework for this distinction. New information was taken to pass through visual, auditory, or haptic sensory registers and pass through a short-term memory store where information could be rehearsed and passed on to a permanent long-term store. However, experimental data proved difficult to reconcile with the modal model. Towards the end of the 1960s the analysis of neuropsychological patients had provided clear evidence pointing towards at least two memory subsystems consisting of long and short term memory. Milner (1968) reported a hippocampal amnesic patient ‘HM’ who demonstrated poor performance on long-term memory tasks, whilst retaining performance on digit span and other short-term retention tasks. Shallice and Warrington (1970) described a patient ‘KF’ that exhibited intact long-term and impaired short-term memory performance, thus highlighting a double dissociation between long and short-term memory stores. KF also had intact visual short-term memory. This evidence demonstrated that damage to short-term memory did not prevent access to long-term memory, and damage to verbal short-term memory did not affect visual short-term memory, neither of which would have been predicted from the Atkinson and Shiffrin proposal.

A more detailed framework that took into account the type of information being presented was necessary. Baddeley and Hitch (1974) provided evidence that a verbal short-term memory system was separate from general control and attentional processes, and Baddeley (1983; 1986) proposed two domain-specific memory stores concerned with storing visual or verbal information and an amodal central executive concerned with attentional control. All three systems were limited in capacity. The phonological store was taken to hold speech and acoustic information, and rehearsal
of this information could be through vocal or sub-vocal repetition of information. The visuospatial sketchpad was assumed to support mental imagery and to store visual and spatial information on a temporary basis. Logie (1995) suggested a further separation between a temporary visual store, the visual cache, and a temporary store for movement sequences, the inner scribe which also provided a rehearsal function for the visual cache. The operation of the inner scribe has been linked to arm movements (e.g. Smyth & Pendleton, 1990) and eye movements (e.g. Pearson & Sahraie, 2003; Postle, Idzikowski, Della Sala, Logie, & Baddeley, 2006). The central executive was taken to be a limited capacity attentional pool responsible for processes beyond that of storage and rehearsal, such as task switching and response inhibition. Therefore, one of the central tenets of the Multiple Component Model is that executive control processes are distinct from temporary memory that is supported by separate domain-specific short-term memory systems. Verbal information is stored in the phonological store and visual information is stored in a visuo-spatial temporary memory system (Baddeley & Hitch, 1974; Baddeley, 1986; Baddeley & Logie, 1999). Therefore it is possible for participants to perform concurrent visual and verbal tasks with little, if any decrement in performance, whereas two tasks from the same domain will lead to a decline in task performance (Logie, Zucco, & Baddeley, 1990; Cocchini, Logie, Della Sala, MacPherson, & Baddeley, 2002).

The majority of early research into the model focused on the phonological store due to the ease with which encoding and maintenance could be explored experimentally. Typically participants would be given a task that involved recalling a sequence of letters or numbers. They would also be required to perform a secondary task such as repeating a series of digits aloud (articulatory suppression) (e.g. Baddeley, Lewis & Vallar, 1984). Key outcomes of early research into the phonological loop which led to its subsequent fractionation include the finding of the word length effect (Baddeley, Thomson, & Buchanan, 1975), the phonological similarity effect (Conrad, 1964; Baddeley, 1966), and the irrelevant speech effect (Salamé & Baddeley, 1982). Baddeley et al. (1975) demonstrated the word length effect in a series of experiments assessing recall for long and short words using visual and auditory presentation. In the first experiment participants were tested for word recall using lists of one syllable words (e.g. sum, hate, harm, wit) and five syllable words (e.g. association, opportunity,
representative) that were presented auditorily. The percentage of words recalled was reliably higher for the single syllable lists. This was replicated in subsequent experiments where long and short words were derived from the same category (names of countries), and with visual rather than auditory presentation. The addition of articulatory suppression removed the word length effect for visually, but not auditorily presented information. Baddeley et al. (1975) suggested that the word length effect was the result of the limited capacity of an articulatory rehearsal loop.

The phonological similarity effect had been demonstrated prior to the development of the 1974 Baddeley & Hitch model. Conrad (1964) and Baddeley (1966) both demonstrated a negative effect of acoustic similarity on recall performance for word lists (Both auditorily and visually presented) Salamé and Baddeley (1982) demonstrated that accompanying visually presented verbal information with irrelevant sound (both speech and nonsense syllables) leads to a decrement in memory performance. The amount of interference from irrelevant speech was partially determined by the level of phonological similarity between irrelevant and to-be-remembered information. This irrelevant speech effect was removed by the addition of articulatory suppression (For an alternative interpretation of the irrelevant speech effect see Jones & Macken, 1995). Baddeley et al. (1984) demonstrated that the phonological similarity effect is not abolished by articulatory suppression regardless of whether this suppression is conducted at presentation, or recall of information. As an extension of the results of Baddeley et al. (1975), it was also demonstrated that the word length effect was abolished with both auditory and visual presentation under articulatory suppression when the suppression was conducted throughout presentation and recall. The series of experiments presented above lead to the conclusion that the phonological system of the MCM must contain a phonological store, to which auditorily presented information gains direct access and that is disrupted by the phonological similarity effect. There is also a rehearsal loop that is responsible for the word length effect.

Whilst the above research represents a very small percentage of the work that has been carried out assessing the workings of the phonological loop, it does highlight the precision with which the experimental method and the MCM can highlight specific
processes within a theoretical framework. The method has had similar success in identifying the parameters of a corresponding visual framework. Baddeley (1983) suggested a visuo-spatial scratch pad (VSSP) which was responsible for creating and maintaining visual imagery. Early work involving the VSSP (e.g. Baddeley, Grant, Wight & Thomson, 1975; Baddeley and Lieberman, 1980; Logie, 1986; 1995; Quinn & Ralston, 1986) was based on the assumption that visual memory may have an analogous framework to that of the phonological loop. Logie (1986) demonstrated that visual material gained access to a visual store in a similar manner that phonological information gained access to the phonological store. Logie, Zucco & Baddeley (1990) demonstrated that short-term verbal and visual memory stores were separable components by showing domain specific interference on visual and verbal memory tasks. It was shown that there was greater interference on a visual matrix task from interference tasks involving visuospatial material than from a task involving mental arithmetic. The opposite effect was seen for a verbal memory task.

With the identification of a distinct visual system, research developed around the concept of fractionation within the VSSP. Logie (1995) described a system where visuo-spatial working memory contained a visual cache that was a store for static images, and an inner scribe, that was involved in the encoding and maintenance of spatial sequences. Following this distinction, it was suggested that the concept of a single visuospatial sketch pad should be replaced with the concept of a visuospatial working memory (VSWM), which allows more for the concept of storage and rehearsal of different types of visual information. The argument for fractionating the visuo-spatial system of the Multiple Component Model was demonstrated by Logie and Pearson (1997) who demonstrated a differential developmental trajectory of visual and spatial short-term memory. Children aged 5-6, 8-9 and 11-12 undertook visual and spatial tasks. Performance was better on the visual task across all groups, and this gap grew larger as the children developed, providing evidence for a separation of visuospatial working memory, incorporating a visual cache and an inner scribe.

This differentiation between a visual and spatial-sequential temporary memory system was also demonstrated in adults by Della Sala, Gray, Allamano, Baddeley and Wilson.
(1999) in a study assessing the possible double dissociation of interference procedures on visual and spatial memory tasks. The two memory tasks used were the visual patterns task (VPT), and the Corsi blocks task. The VPT is a static matrix task where participants are presented with a grid containing 50% black squares and 50% white squares. The task is to recall the location of the black squares on progressively larger grids until the point at which participants can no longer correctly recall the patterns presented. A span measure, which is usually the mean number of squares in the last 3 correctly recalled patterns, is taken. The VPT is taken to be a test of static visual memory and therefore a measure of the capacity of the visual cache. Similar matrix tasks had been commonly used to measure visual memory prior to the development of the VPT (Phillips & Christie, 1977: See Wilson, Scott & Power, 1987, for a demonstration of a span measure). The Corsi blocks task is taken to be a measure of memory for spatial location and sequences (Baddeley, 2007; Logie, 1995). The experimenter and participant sit either side of a board with wooden blocks distributed around it. The experimenter taps out a pattern which the participant is expected to recreate. As with the VPT the procedure continues with longer and longer sequences until the participant is no longer able to correctly recall the sequence and then a span measure is calculated. In the Della Sala et al. (1999) study, the two interference procedures were the presentation of irrelevant pictures featuring abstract works of art, a task that is taken to disturb the visual store (Logie, 1986) and a peg sequence task. The latter requires participants to tap in sequence along a series of pegs placed around the edges of a wooden board that was obscured from view. This task, with its spatial-sequential component was taken to involve the inner scribe (Smyth, Pearson & Pendleton, 1988). Using a within subjects design participants were required to undertake control versions of the VPT and the Corsi blocks task in order to identify their maximum performance level. They were then required to undertake 4 experimental conditions where they performed each memory task twice. In one case whilst performing a visual interference task, and in one case whilst performing a spatial interference task. Performance on the 4 experimental conditions was calculated as a percentage of performance in the single task control conditions. A double dissociation was found, whereby the irrelevant pictures interference task had a greater interference
on the VPT than it did the Corsi blocks task, and the pegword interference task had a greater effect on the Corsi blocks than it did on the VPT.

Whilst the visual and verbal memory systems are defined as separable components, there are occasions where cross-modal encoding can interfere with maintenance or recall of information. One such instance is the visual similarity effect. Recall of visually presented verbal items is affected by the visual similarity of the items presented. For example, Logie, Della Sala, Wynn, and Baddeley (2000) presented participants with sequences of letters that were a mix of upper and lower case characters with the aim of recalling the sequences in the correct order, and the correct case (participants were also required to carry out articulatory suppression in order to reduce the level of verbal encoding). Performance was poorer on sets where upper and lower case versions of the letters were visually similar, (e.g. Kk, Cc, Zz and Ww) compared to patterns where upper and lower case letters were visually dissimilar (e.g. Dd, Hh, Rr & Qq). Saito, Logie, Morito, and Law (2008) also demonstrated that there is a level of visual encoding in predominantly verbal recall tasks. Participants displayed a visual similarity effect when recalling visually presented Japanese Kanji letters if recalling from lists where characters were visually similar, regardless of whether they were phonologically similar or dissimilar.

Whilst research into the storage subsystems of the MCM has yielded a theoretical framework with further fractionation and mapping of the model, research into the central executive has been slower to develop. It is highly likely of course, that this is due to the complexity of the tasks it is posited to be responsible for. Initially the Supervisory Attention System (SAS) of Norman and Shallice (1986) provided the framework for central executive function explored in Baddeley (1986). This posited a two part system of attention, one that is automatic and relies on current knowledge, the other focusing on attentionally demanding tasks such as focusing the limited capacity of attention, dividing attention, or switching attention from one task to another (Baddeley, 1986; 1996). Central executive performance is taken to be linked to the frontal lobes, specifically in the dorso-lateral pre-frontal cortex (Smith & Jonides, 1997; Kane & Engle, 2002), but behaviourally the mechanisms that are at work are still unclear. Of the four proposed functions of the central executive mentioned above,
the need to focus attention is most comprehensively described by a separate model of working memory function. The Embedded Processes Model (Cowan, 1988, 2005) posits a limited capacity focus of attention that can hold 4 ‘chunks’ of information. The complementary links between the MCM and the Embedded Processes Model will be discussed at length later in this chapter. Experimental research based on the theoretical framework of the MCM looking into executive function has conventionally followed the same selective interference paradigm seen in studies assessing the architecture of the short term stores (e.g. Rudkin, Pearson, & Logie, 2007). Specifically studies assess memory performance alongside the performance of secondary tasks that are designed to tap the functions of executive performance as outlined by Baddeley (1986), and as a control, along with secondary tasks that are not executively demanding. A disproportionate decline in performance when carrying out an executive secondary task is taken as evidence for there being a requirement of the use of the central executive in the memory task. This in turn leads to understanding about the mechanisms that facilitate task performance.

The limited capacity of focused attention has been demonstrated using secondary interference tasks that are designed to require some form of updating, or knowledge of previous actions. Articulatory suppression, which disrupts sub-vocal rehearsal in the phonological loop does not have the properties of an executive interference task, as it simply requires the utterance of repeated sounds. A task such as random number generation (RNG), or counting backwards in sevens demonstrates the properties needed for an executive secondary task, as they require the individual to monitor the already produced information in order to stick to the longer term goal of the task (See Baddeley, 1966a for the first example of this task; Baddeley, 1986, p231). Using this method it is possible to demonstrate if a level of executive function is required in certain memory tasks. In a series of studies looking into visual and spatial memory task performance, Rudkin, Pearson, and Logie (2007) demonstrated that tasks with a spatio-sequential component involved more recruitment of central executive processes than a static visual task. Using a paradigm similar to that of Logie & Pearson (1997) participants undertook static visual, and sequential-spatial memory tasks, with a simple articulatory suppression, and an executively demanding random number generation task. It was found that the spatio-sequential memory task performance
suffered more than static-visual memory performance compared to single task performance when accompanied by the executively demanding secondary task. This was not simply a function of the spatio-sequential task requiring a greater use of general resources. There were no differential effects of performance in either memory task when performed with articulatory suppression. It is therefore possible that the need to update memory performance in the RNG task, and the need to update memory for sequences represent the function linking working memory to long-term memory outlined by Baddeley as a component of central executive function.

Baddeley (2007, p118) considered the problem of positing the central executive as a form of homunculus, where all aspects of working memory performance that could not initially be explained in terms of storage or rehearsal would be located. Whilst this is initially unproblematic, as it allows research to continue developing without stagnating on a particular point, it is a problem that only directed research into executive function can address. This requires an attempt to describe the functions that are ascribed to the homunculus. As such framing central executive function as a focus of attention allows for testable research into this system and as will be seen in this chapter allows for consistency with other models of working memory (Baddeley, 2007, p117; Cowan, 2005, p73).

The Baddeley (2000) model featured the addition of an episodic buffer. This was posited as a limited-capacity system which had access to long-term memory and held multidimensional representations of information. This allowed information from long-term memory, or information with semantic meaning to supplement the information held in the traditional short term stores (Baddeley & Wilson, 2002). Whilst the episodic buffer is the newest addition to the MCM, it is important in the assimilation of the MCM view of working memory with that of other models. Most of the research carried out by Baddeley and colleagues to explore the episodic buffer have involved tasks involving temporary memory for visual arrays of shapes and colours that had previously assumed to be a function of the Visuo-Spatial Sketch Pad (e.g. Allen, Baddeley & Hitch, 2006). Further functions of the episodic buffer, and it’s relation to other models of memory will be discussed throughout this chapter (See figure 1.1 for a recent version of the MCM).
Research that is based upon the MCM is predominantly concerned with a bottom-up interpretation of working memory, where sub-systems are identified and fractionated through interference tasks in order to identify the exact processes at work. This approach obviously has its merits, and experimental data has shown that there are clear distinctions between visual and verbal stores (Logie et al., 1990), between visual and spatial stores (Della Sala et al., 1999; Logie & Pearson, 1997) as well as differences in the level of executive recruitment required to carry out differing tasks (Rudkin et al., 2007). However, there are other approaches, predominantly emanating from North American research groups in line with a ‘top-down’ assessment of working memory that is predominantly concerned with the measuring the attentional capacity of the individual and the subsequent level of memory performance that can be attained rather than necessarily attempting to identify the distinct systems that lead to this level of performance. Whilst it is often initially taken that these approaches represent conflicting views of the architecture of working memory, it is more likely that they represent differences in approach and research question (Cowan, 2005; Logie, 2011).

Cowan’s Embedded Processes Model (1988, 2005), and the Primary/Secondary Memory distinction outlined by Unsworth and Engle (2006) will now be considered.
Both models will be described, with the key tenets explored. After this the approaches will be considered in relation to the MCM. A framework attempting to encompass key points from all three models will be developed in order to provide a consistent grounding for interpretation of data collected for this thesis.

The Embedded Processes Model

The Embedded Processes Model (EPM) (Cowan, 1988, 1999, 2005; See Figure 1.2) proposes a limited capacity, domain-general ‘Focus of Attention’, that falls in the centre of ‘activated sensory and categorical features from long term memory’ There is also a brief ‘sensory afterimages’ store, which is posited to hold iconic information for around 250 milliseconds. This model sees short-term memory as an activated subset of long-term memory. Cowan (2005, p41) posits that any given task stimuli, such as a visually presented sequence of numbers will lead to an activation of features in long-term memory, such as knowledge for the visual representation of Arabic numbers. The number of items that an individual will be able to recall is determined by the individual’s scope of, and control of, attention. (Cowan, Fristoe, Elliott, Brunner, & Saults, 2006). The focus of attention can be an automatic response to a change in environment, such as diverting attention to a loud noise, or flickering image. The control of attention is voluntary and is demonstrated by tasks such as the anti-saccade task (Engle, 2002) (The task was first developed by Hallett, 1978. It requires participants to divert attention away from a given stimulus by directing the movement of the eyes away from the stimulus). The ability to control this and attend to the to-be-remembered information is taken to be crucial to an individual’s working memory capacity (Kane, Bleckley, Conway, & Engle, 2001). Participants who demonstrate higher working memory capacity are better at controlling attention and directing gaze away from a distracting image than those with a lower capacity (Unsworth, Shrock, & Engle, 2002; Engle, 2002). This distinction between automatic, and controlled attention is similar to the distinction drawn in the Norman and Shallice Supervisory Attention System which, as has been highlighted was used as the basis for Central executive in the Baddeley and Hitch (1974) working memory model.
The EPM suggests a limited capacity for the focus of attention. In a situation where a participant is presented with familiar information, and the opportunity for rehearsal of information is prohibited either through interference or manipulation of presentation times that each item will represent one ‘chunk’ of information (Cowan, 2005, p40). Cowan (1988) suggests that individuals can typically recall between 3-5 items of information. It is suggested that this represents a limit of the focus of attention rather than of activated memory. Unconscious priming (whereby masked information can still have a semantic effect on subsequent presented words) (Draine & Greenwald, 1998; Marcel, 1983) suggests that not all information in activated memory is held within the focus of attention. Cowan (2005, p45) provides the example of a visual mask placed after a consciously undetectable visual presentation of the word dog. This increases the chances of a semantically related response, such as cat, compared to no word being presented prior to the mask. If all activated memory were held in the focus of attention it should not be possible for information that the participant is unaware of, to semantically prime future responses.

It is also posited that there is a flexibility within the focus of attention, Cowan suggests that the focus of attention can be ‘zoomed out’ to focus on a large number of easily recognisable items, but ‘zoomed in’ in order to focus on a smaller number of difficult to recognise items. The EPM posits a system of resource sharing between storage and processing functions within working memory (Cowan, 1995). The interplay between the storage required by focusing attention, and the processing required by controlling attention is posited to differ between individuals depending on their knowledge of the task, or their individual ability (Cowan, 2001).

In brief, there are two main aspects of the EPM to be considered. The first is that the presentation of information leads to information from long term memory being held in an activated state. The second is that a subset of this activated information is held within the focus of attention, and that this represents the capacity of working memory. A key issue for future research, highlighted by Cowan is the question of the relationship between capacity (focus) and control of attention. Does a stronger control of attention lead to an improved capacity, or are the two functions covariable simply due to being part of the overall cognitive system of the individual? What is not in
question is that a stronger control of attention is related to higher working memory
capacity (Kane et al, 2001), which in turn is related to a higher cognitive task
performance (Cowan et al. 2006).

It is obvious that the approach to working memory performance seen in the EPM is
different from that seen in the MCM. One notable difference is the approach to
processing and storage. The EPM suggests a resource sharing of processing and
storage, whereas Duff and Logie (2001) have demonstrated that processing and storage
are separable abilities, within individual parts of the MCM. These issues are not of
course, insurmountable; Cowan suggests that developments within the MCM, such as
the episodic buffer have alleviated many of the differences between the models.
Certain tasks, such as binding of features are posited to be highly demanding of the
limited capacity attentional system of the buffer (Baddeley and Wilson, 2002), this
may represent the same process as the ‘zooming in’ of the focus of attention outlined
by Cowan. The focus of attention is also similar to the buffer, in that it can account for
the role of long-term memory in maintaining information within MCM (Baddeley,
2007, p153). In other words, it prevents the MCM from being a constant blank slate
provided with new information, and allows the activation of previous knowledge in
order to alleviate the strain of maintaining information through a process of rehearsal
at all times. (It is pertinent to note at this point that Allen, Baddeley & Hitch (2006)

Figure 1.2 Cowan’s 1988 Embedded Processes Model, as represented in Cowan (2005).
demonstrated that bound information could be held in the episodic buffer without incurring an attentional cost. It may therefore be that the buffer is loosely analogous to the activated long-term memory aspect of Cowan’s model.

There are aspects of the EPM that remain unspecified, such as the link between control and focus of attention. There are also experimental results such as domain specific interference (Logie et al. 1990; Cocchini et al. 2002) which do not fit with the model. However, these do not detract from the model’s usefulness in identifying possible mechanisms for individual differences in working memory performance. Indeed as Baddeley (2003) suggests, it was the simplicity of the original MCM that gave the scope for further investigation and has allowed it to be researched so thoroughly. Therefore it is likely that future views on working memory will be based on an understanding of both the separability of visual and verbal information, and an understanding of how they contribute to and consume the capacity of the focus of attention.

Individual Differences in Working Memory

The third theoretical concept considered in detail is that of the distinction between Primary and Secondary memory outlined by Unsworth & Engle (2006). This in itself was developed from the work of Engle, Tukholski, Laughlin, Conway & Engle (1999), and Kane, Bleckley, Conway & Engle (2001). Like the EPM this is an approach based on the concept of controlled attention as a measure of working memory capacity. However through assessment of the types of mistake elicited by certain tasks, an element of fractionation between simple and more complex tasks, in line with the parameters of the MCM is posited. Overall this is an approach to working memory structure based on an understanding of the relationships between separate tasks, and how these may change between participants of differing cognitive abilities. The research of Engle et al. (1999) is framed by a slightly different research question to that of Baddeley & Hitch (1974) and that of Cowan (1988). Engle et al. (1999) sought to identify to what extent the terms short-term memory (STM) and working memory (WM) refer to the same construct. They pointed towards an ambiguity within the field as to whether STM and WM are separable, whether one is a subset of the other, or whether they are the same thing. In the Engle et al. (1999) model, STM is a subset of
overall WM. WM is completed by a central executive structure and a ‘Grouping Skills’ ability. It is suggested that the STM component consists of the ‘activated memory’ posited by Cowan, This could also be taken to be analogous to the phonological store and the visual cache of the MCM. The central executive maintains activation towards specific aspects of to-be-remembered information in a similar manner to the focus of attention in Cowan’s model. The grouping skills section could be seen as being analogous to the rehearsal processes of the phonological loop and inner scribe within the MCM. However, unlike the earlier versions of the MCM, the level of familiarity of the stimuli, and/or previous knowledge is posited to be a moderating factor in the amount of attention needed to be used for rehearsal or grouping. This could be commensurate with the episodic buffer in later versions of the MCM (Baddeley, 2000) (See fig 1.3 for the Engle et al. 1999 model).

Engle et al. (1999) suggest that no given memory task is process pure, and that any given task can rely on all components of the memory system outlined above. For example, Daneman and Carpenter’s (1980) WM Span task, where participants are asked to answer a series of questions whilst also maintaining the last word in each of a series of sentences would rely on the STM component to activate not only the words that are to be remembered, but the stored knowledge needed to answer any concurrent question. The central executive component would be needed to direct attention to the aspect of the task that is currently being undertaken. Finally the Grouping Skills/Rehearsal Procedures would be needed to maintain the list of words that are to be recalled. It is suggested that tasks such as word list recall will involve executive processes to a lesser extent than a task such as the Daneman and Carpenter (1980) WM Span task. Using latent variable analysis Engle et al. tested the assumptions of this model. Participants performed 11 memory tasks, including ‘STM’ tasks such as forwards and backwards word span, WM span tasks such as Operation Span (remembering a list of words interspersed with simple mathematical equations) and Reading Span (remembering a list of words interspersed with valid/nonsensical sentences). Measures of fluid intelligence (Gf) (Cattells Culture Fair Task and Ravens Progressive Matrices), were also taken. WM and STM were found to reflect separate, but highly related abilities. WM tasks and Gf tasks were also found to be related. The authors suggested that WM and Gf tasks represented an ability to control attention. It
is also possible that this is what separates STM and WM task abilities. The shared variance may be attributable to an ability to activate LTM, or to store new information, whereas the separability could be associated with the need to control the focus of attention in WM tasks. This corresponds with Baddeley’s (1996) suggestion that the central executive of the MCM does not in itself involve storage.

Engle et al. (1999) provide a model of the processes undertaken by individuals during memory tasks that is commensurate with both the suggestions of the MCM and the EPM. However, much like the EPM model, the paper is based on an attempt to understand the relationship between a number of factors in order to map the overall workings of the system, rather than a focus on how an individual task taxes specific elements of the system in the manner of the MCM. Unsworth and Engle (2007a) addressed this problem by analysing the types of errors made in a number of tasks in order to assess the mechanisms at work. Using a definition of either simple (e.g. word list recall) or complex (e.g. operation span) tasks the effects of specific interference and phenomena were assessed. It was found that articulatory suppression, the word length effect, and list length affected both simple and complex span tasks. However there was a more pronounced effect in simple tasks. It was posited that this reflected the increased reliance on verbal rehearsal processes in simple tasks, compared to complex tasks when rehearsal is not always possible. Further evidence for the separation of task processes came from the type of errors made in simple and complex tasks. Simple tasks commonly elicited errors of item order. Rehearsal had maintained item information, but a measure of serial order had decayed over time. In complex tasks mistakes tended to involve omissions of lost information, suggesting that an inability to rehearse, or attend to information had led to forgetting. The authors suggest that simple and complex span tasks are supported by common storage systems, but there are underlying processes such as maintenance and controlled attention that differ between tasks.
Unsworth and Engle (2006) had suggested that a dichotomous definition of tasks as either ‘simple’ or ‘complex’ should be avoided. Previously Engle et al. (1999) had suggested that no task is process pure as all tasks require separate components to be successfully completed. Furthermore they state that there are likely to be differences between individuals in what constitutes a simple or complex task. Unsworth and Engle (2006) thereby proposed a possible theoretical account for the methods by which ‘simple’ and ‘complex’ tasks are performed. Performance on a task that is taken to be a simple, or short-term memory task is mainly determined by primary memory (PM). Unsworth and Engle propose that this is around 3-5 items of information, in line with the suggestions of Cowan (2001). However PM could possibly also be taken to be analogous to the phonological store and visual cache of the MCM. However, an increasing list length, or a need to carry out an interpolated processing task would lead to the recruitment of secondary memory (SM). This is complementary to the Engle et al. (1999) finding that the correlation between simple and complex span tasks increases with list length. Participants that are able to recall a long list of letters/words in a simple
task are likely to be using similar rehearsal and maintenance processes that are necessary for complex tasks.

Overview of Working Memory Models

These three major models of working memory function initially appear to offer differing ideas on the architecture of the system. However, an examination of the literature shows that for the most part, these differences are ones of definition and research question, (Baddeley, 2007; Cowan, 2005, p48; Logie, 2011) rather than interpretation of human task performance. It is also worth noting that, individual differences in task performance aside, any differences in interpretation of task performance are likely to be linked to differences between research groups, rather than any actual changes in the way participants perform tasks between separate research laboratories. As the field has progressed through forty years of research since Baddeley and Hitch’s (1974) publication, the Multiple Component Model has developed and there are now areas of theoretical framework between all three models presented here that could be taken to be complementary to one another.

It is also apparent that each model has its own specific strengths. The MCM has proved invaluable as a framework for identifying specific memory stores and the manner in which information from the outside world enters the human brain. The large body of research using interference and dual-tasking has demonstrated separate visual and verbal memory systems (Cocchini et al., 2002; Logie et al., 1990). Separate rehearsal and storage systems within these have also been identified (Baddeley et al., 1984; Della Sala et al., 1999; Logie, 1995). The addition of the episodic buffer, working in conjunction with the central executive has allowed room for research into multidimensional encoding to continue within the framework of the MCM (Baddeley, 2000). However, this new addition has also opened the door for the integration of the top-down, attentionally driven model of Cowan (2005) to the MCM. The EPMs emphasis is on the ability of the individual to activate previous knowledge and focus on relevant information and allows research to consider what information is held in working memory, rather than where information is held. Non-conscious priming and
the ‘Cocktail party’ effect (Conway, Cowan & Bunting, 2001) demonstrate that individuals focus on a subset of information, but that information can be activated without conscious awareness. The ability to focus attention to activated information appears to be compatible with definitions of the MCM’s central executive. The Engle et al. (1999) model brings together the rehearsal and storage aspects of the MCM and the focus of attention/activated memory aspects of the Cowan model. Its key addition to the literature is the inclusion of individual differences within all definitions. Engle et al. move away from the dichotomy of STM/WM, storage/processing or simple/complex tasks, suggesting that the nature of task processes depends on the ability of the individual. This is further explored by the Unsworth and Engle (2006) model of primary and secondary memory. The analysis of omissions and intrusions in order to identify the transfer between PM and SM could be complemented by the selective interference paradigms typically used by those engaged in MCM research. The system of PM may be analogous to the memory stores of the MCM whilst the SM system may represent the need for updating and focused attention that are the characteristics of the central executive and EPM.

As previously stated the purpose of this thesis is not to provide evidence for or against any theoretical framework of information processing. Three major models of working memory have been explored so as to provide a broad understanding of the working memory literature. These definitions will be necessary in order to understand any changes in the processes underlying task performance across the lifespan. There is common ground between the three models that will be explored through the experimental results demonstrated in this thesis. The authors of the three models here have suggested that whilst there are differences in emphasis, the experimental data in the literature can complement all three, and any interpretation of data in this work will try to take this into account.

A consideration of the working memory literature, both related to individual ability, and age-related change will be seen later in this chapter. Prior to this an overview of cognitive ageing research and commonly used frameworks will be provided.
Cognitive Ageing: Methods and theories

The general decline of cognitive performance with age is a well-documented and broadly researched phenomenon (Cattell, 1943; Deary et al. 2007; Hebb, 1942; Salthouse, 1996). As mentioned in the introductory paragraphs, in order to maintain a focus of research, this thesis is concerned with the rejection of the ‘dull’ hypothesis in regards to short-term and working memory tasks. That is, rejecting the idea that cognitive decline is simply a case of older adults performing more poorly than younger adults on a variety of tasks. A simple view of ageing as a general decline does not provide information on the underlying processes affecting performance. Whilst this may have the benefit of simplicity, it is of little use if one is trying to identify specific areas of or reasons for decline.

There are of course, differing methods of ageing research which, although working towards the same goal of understanding the nature and severity of decline in healthy and impaired older adults approach the research question in different manners. Perfect and Maylor (2000) describe the two major methodological approaches to the study of cognitive ageing as the predominantly modular, localist, experimental approach, and the general, correlational approach. Exponents of the experimental approach commonly seek to identify specific processes within cognitive tasks that change differentially with age. Exponents of the correlational approach typically assess performance on a number of tasks that are taken to measure cognitive function and assess changes in the relatedness of the tasks with age.

The experimental approach can also be framed as the ‘ANOVA’ approach, as the typical research paradigm would involve a between-groups experiment with young and older adults taking part in a form of cognitive task with and without some form of interference/distractor task. Results that reject the dull hypothesis would involve some form of age x task interaction, where the manipulation on task performance has differing effects on the two age-groups measured. Alternatively, the absence of any age-related effects could suggest the absence of any age-related decline in the given task. Beigneux, Plaie, and Isingrini (2007) demonstrated the first of these by demonstrating an ‘age-group’ x ‘presentation method’ interaction when testing adults
on a visual working memory task. Participants were presented with matrices consisting of black and white squares with the goal being to recall the location of the black squares. The experimental manipulation involved a static presentation of all the squares in the matrix at once or presentation of the black squares sequentially, one after each other. There was a clear effect of age-group, and of the manipulation. The age effect alone could be taken to be evidence for the ‘dull’ hypothesis, in that young adults outperformed older adults. The effect of the manipulation showed both age-groups performing significantly better on the static task compared to the sequential task. However the key finding of the ‘age-group’ x ‘presentation method’ interaction demonstrated a greater decline between static and sequential task performance in young adults compared to the older adults. There are of course numerous possible interpretations of such a finding. It may suggest that younger adults have a greater level of performance to lose between the two tasks; it may suggest that older adults experience such total decline in visual memory performance that they are unable to maintain performance in any form of visual task. Of course, no single experiment can map the complex underlying processes at work in such tasks. But the presence of the age-group interaction does demonstrate that the effects of ageing are not equal across all tasks, and that a nuanced approach to ageing research can reveal differential effects of ageing.

Logie et al. (2004) used the experimental approach to cognitive ageing to demonstrate a lack of age-related decline in dual-tasking ability once the single-task ability of each individual had been controlled for. Both young and older adults were measured for digit recall span and visuo-motor tracking span. The tasks were then performed concurrently, with one task being performed at the individual’s span level, whilst the other was manipulated to be either above, or below their span. Results demonstrated that young and older adults could successfully perform two tasks at once as long as neither task exceeded their own span level. If one task was being performed above span and the other being performed at span then performance in the above span task would decline, but not in the ‘at’ span task. For both age groups changing span level only affected the task being changed, and not the task that was being held constant at span. This absence of age effect once individual ability had been accounted for demonstrated that whilst the storage capacity of older adults may have declined (As
demonstrated by lower single task capabilities), the specific dual-tasking ability did not decline with age. In a recent review chapter, Logie, Horne, and Pettit (2015) cite this as evidence rejecting the dull hypothesis due to the lack of decline seen in older adults.

Whilst the method of experimental manipulation does allow for the development of specific research questions, simply increasing the specificity of what we know does and does not decline in ageing may lead to simply refining the question being asked, without ever approaching a definitive answer (Salthouse, 1984). An ever increasingly precise method of assessing cognitive function must also be aware of concerns over the process purity of cognitive tasks. Engle et al. (1999) have stated that it is unlikely that any cognitive measure is a completely precise measure of the cognitive function it is designed to measure. It is likely that there are issues of multi-dimensional storage of information, as well as contributions from both short-term memory storage, and long-term memory storage in numerous working memory tasks. Unsworth and Engle (2007a) showed that the correlations between simple and complex short term memory tasks increased with increasing performance. This suggests the mechanisms used by those performing tasks at a high level, are different from the mechanisms used when performing a task at a lower level. Whilst these are issues that arise with an experimental approach to cognitive ageing, they are also issues that can be assessed using the experimental approach through selective interference tasks and an awareness of individual differences in levels of task performance. The Beigneux et al. (2007) and Logie et al. (2004) examples considered earlier demonstrate that the experimental method can be manipulated in order to identify complex processes that underlie a simplistic overall measure of task performance.

A further key issue for the experimental approach to cognitive ageing is that of differences in proportional change. In an echo of the process purity issue just discussed there is the consideration that measuring two populations with different levels of performance on the same scale, and then comparing changes based on that scale may not be statistically correct. Take a hypothetical situation where a younger adult can recall 8 items and an older adult can recall 5 items in a single task. In a subsequent interference-task condition the younger adult can now recall 5 items, and the older
adult recalls 2. In absolute terms both participants have recalled 3 fewer items than they could in the single task condition. However the older adult has suffered a 60% decline in performance compared to a 40% drop for the younger adult. What are we to conclude from this? As Verhaeghen (2000) states, reviewers can easily, and often do come to different conclusions based on the same corpus of work. Our hypothetical example could lead one to conclude that young and older adults show equal levels of decline as both recall 3 items fewer in an interference condition. Alternatively you could pronounce that older adults show an interference effect that is a third bigger than their younger counterparts. This of course is not an insurmountable issue, nor is it one that is confined to research into cognitive ageing. It is however something that must be taken into account when assessing data in many common working memory tasks where the relatively small number of items that can be recalled drastically increase the difference between failing to remember one or two items of information.

The experimental approach is of great use to research into cognitive ageing as it allows for researchers to manipulate specific tasks in order to understand behaviour between age-groups. The alternative, correlational approach typically assesses performance in large-scale longitudinal or cross-sectional studies on a number of cognitive measures. Manipulations or independent variables tend not be based on the tasks themselves but at a group-level. Often these are based on risk factors such as smoker/non-smoker, male/female, IQ scores etc… (See Batty, Deary, Schoon & Gale, 2007: Deary, Weiss & Batty, 2010). If the correlation between a number of tasks differs between young and older adults then this can be taken as evidence for rejection of the dull hypothesis (Perfect and Maylor, 2000) Referring back to the Wilson et al. (2002) study cited earlier in this review, the general decline of a series of memory tasks represented support for a ‘dull’ hypothesis of ageing, however the differences in correlations due to age at the beginning of the study suggested that ageing is not simply a linear decline. Those who subscribe to the correlational approach are often concerned with the concept of a general factor referred to as fluid intelligence (Gf) derived from common scores across a number of tasks, with the view that ageing can be represented by a decline in this factor (See Deary, Whalley, & Starr, 2009). Large scale correlational studies tend to rely on global measures such as IQ that are based on the common variance between collections of tasks. Whilst this is invaluable in identifying directions
for research, data such as residual variance is often treated as noise within the data set. However, this misses the possibility that there are multiple differing cognitive functions that contribute to an overall cognitive ability in addition to the common variance.

There are of course methodological issues with correlational or regression based studies. Not least the basic premise that correlation is not causation (Perfect & Maylor, 2000). This issue is especially pertinent when referring to cross-sectional studies, where any difference in age-groups may represent not only task ability, but cohort effects, education effects and lifestyle factors. Furthermore an association between two tasks may suggest that the tasks are related, but does not mean that the tasks are the same. A simple example would be a correlation between declines in a Tower of Hanoi task, and a written verbal fluency task. This may reflect a decline in a general factor leading to poorer performance in two very different cognitive abilities; alternatively it may represent a decline in motor control that acts equally on both tasks. As with the experimental approach there are the same issues with process purity that have previously been discussed. However, due to the inability to use selective interference to identify underlying processes, this problem can be exacerbated in the correlational literature. It would be prudent for the methodology of cognitive ageing research to find a complementary middle ground between the general, correlational approach and the specific, experimental approach.

Having given a brief overview of the two major methodological approaches to cognitive ageing, three major theoretical approaches of cognitive decline will be explored. As with previously discussed concepts in this review, they will be looked at with regards to their relevance in studies of working memory, rather than in a broader sense of cognition as a whole. The ubiquity of cognitive decline has, understandably led to a large number of theories regarding the processes of decline. The three models of ageing presented here are by no means exhaustive, but they do represent differing yet complementary approaches to ageing decline.
Processing Speed and Age

Over the last two decades, one of the most influential theories of cognitive ageing has been the ‘Processing Speed Theory of Adult Age Differences’ (Salthouse, 1996; See also Salthouse, 1985 for early measures of slowing cognition in ageing). The processing speed theory is based on two major assumptions. The first is that the decline seen across cognitive tasks with age is due to constraints on relatively general processing abilities. The second is that the speed of processing is critical in these general processing abilities, and that the speed with which tasks can be carried out declines with age. It is posited that a decline in neural processing speed with age means that older adults require more time to carry out tasks compared to young adults. The cumulative effect of this is to lower overall memory capacity. Whilst this is a theory which suggests a general decline affecting ageing, Salthouse suggests that a general mechanism of decline does not mean all tasks will be equally affected by a decline in processing speed. Salthouse uses the example of portraying the decline in processing speed as a reverse form of the increase in the performance of computers. Whilst advances in processing capability have had a major effect on the improvement of home computers, computers are also operating with advanced versions of their original programs. Therefore older adults may not only be performing all tasks more slowly, but this may be affecting different tasks in different ways. It may even lead to the strategies by which tasks are being performed in a qualitatively different manner in order to allow for declines in processing speed (Salthouse, 1985). As the processing speed theory has developed, so too has the assumption that decline in processing speed affects differing abilities in different manners with age. Finkel, Reynolds, McArdle, and Pederson (2007) took longitudinal data from the Swedish Adoption study of Ageing incorporating scores from 806 participants over a 16 year period in verbal, spatial, memory and processing speed tasks. They found that processing speed was a mediating factor in fluid abilities, but not crystallised abilities. As such, processing speed was related to the memory and spatial tasks, but not the verbal tasks.
Inhibition Deficiency Theory

The Inhibition Deficiency Theory of Ageing (Hasher & Zacks, 1988; Kane, Hasher, Stolzfus, Zacks & Connelly, 1994) is based on a literature which suggests that non-target items in any given task are not ignored, but specifically unattended to; in that there is an active executively demanding mechanism which an individual will use in order to keep an item out of explicit attention. (Tipper, 1985; Tipper & Cranston 1985). Hasher and Zacks suggest that the mechanisms which prevent items being selected in working memory performance in younger adults are deficient in older adults, therefore leading to impaired performance due to an inability to distinguish between intentionally, and unintentionally activated information. Experimentally this impairment in inhibition in older adults is demonstrated by a lack of a suppression effect. Demonstration of the suppression effect in younger adults typically involves presentation of target and distractor items, with the aim of responding as quickly as possible to a target item. Responses to new target items that have previously been distractor items, and therefore not attended to, are slower than towards target items that have not previously been distractors. This suppression effect (also known as negative priming) is not commonly seen in older adults (Kane et al. 1994). Initial research into the suppression effect demonstrated a slowing of around 10ms in younger adults, Kane et al. (1994) suggested that this relatively small decline may be too weak to identify in older adults who, as discussed are likely to demonstrate not just slower motor performance, but slower processing speeds too (Salthouse, 1996). Kane and colleagues sought to increase the suppression effect in younger adults by using distractor trials with meaningful words, rather than single letters as had been used in previous works (Stoltzfus et al. 1993). This led to an increase in the magnitude of a suppression effect in younger adults and did not translate into an effect for older adults.

Whilst the inhibitory deficit appears to be a contributing factor to decline in performance in ageing, it is unlikely that it is responsible for the general decline of all task abilities. Connelly and Hasher (1993) demonstrated that older adults showed suppression effects for items location, but not their identity. Suggesting that the inhibition deficiency hypothesis only holds true for the nature of an item, not its location. Furthermore. Hedden and Park (2001) demonstrated that the timing of
interference or information that is to be ignored has differential effects on the performance of older adults. Older adults consistently demonstrated greater retroactive interference effects (new material preventing recall of previously presented information) of word pairs that had to be recalled compared to younger adults. This suggested an inability to inhibit activation of new material. However there were no greater proactive interference effects (previously presented material interfering with new) for the older group in comparison with their younger counterparts. This interference from new information, but not from previously presented information could be explained as a deficit of inhibition of new information, and a decay of previously presented information. Retroactive interference is an example of an inhibition deficit, whilst a lack of proactive interference could be evidence of a source memory deficit. However the authors note that the time lapse between previous and new information in the proactive condition was longer than that in standard versions of a word-pair interference task. Suggesting that the inhibition hypothesis may be demonstrated by proactive interference in tasks with shorter presentations. Andres, Guerrini, Phillips & Perfect (2008) provided a counterbalance to this research by demonstrating that there were greater age-related effects on specifically effortful inhibitory tasks compared to tasks that required more automatic inhibitory control. Older adults showed a greater decline in performance on the Stroop task compared to young adults than on a negative priming task. This could be commensurate with a view of lack of control and greater, albeit unsuccessful activation of executive function in older adults such as that put forward by Scaffolding Theory (Park & Reuter-Lorenz, 2009).

Scaffolding Theory

The two models of ageing considered so far focus on individual mechanisms and the effects of their decline on performance in older adults. These are both influential theories in ageing, and will be discussed in even further detail in relation to any relevant findings within this thesis. More recently there has been an introduction of integrative approaches that seek to frame age-related declines in cognitive tasks by behavioural and functional changes in cognition. The Scaffolding Theory of Age and Cognition (STAC) (Park & Reuter-Lorenz, 2009) (See also, Baltes & Baltes, 1990) is
proposed in response to the juxtaposition of declining performance in behavioural
tasks such as those looking at working memory, speed and inhibition, compared to the
increase in frontal activation that is a hallmark of cognitive ageing. In its simplest
terms STAC suggests that as we age, ‘more’ is needed to do ‘less’. The authors suggest
that a healthy response to the challenge of cognitive ageing is a system of
compensatory recruitment. The decline of specific task related mechanisms leads to a
recruitment of areas such as the pre-frontal cortex in order to aid task completion. This
can be seen as an extension of ideas relating to dedifferentiation as laid out by Baltes
and Lindenberger (1997), who suggested that links between formerly separable and
specific abilities (Such as sensory, and cognitive function) increase in their inter-
relatedness with age. STAC takes the view that age-related decline may be the product
of a differential decline in a number of different mechanisms that is similar, but not
identical across individuals. Just as poor cardiovascular health, as characterised by
high blood pressure and increased heart-rate can be caused by factors such as poor diet
caus[ing] the restriction of arteries, or overtly stressful situations increasing cortisol
levels, then poor cognitive health as characterised by poor task performance can be
due to a number of issues, such as decreasing processing speed, lack of inhibitory
process, or a decline in storage systems. The need for cognitive scaffolding and
compensatory recruitment may be analogous to the increasing work rate of the heart
in a situation of bad health.

What then are the functional mechanisms that need compensatory neural recruitment,
and what are the systems that are actually being recruited? Park and Reuter-Lorenz
argue that the decrease in brain volume of areas such as the Caudate, Hippocampus,
and the Cerebellum are compensated for by increased bilateral activation in the pre-
frontal cortex (PFC). Cabeza, Daselaar, Dolcos, Prince, Budde & Nyberg (2004) and
Reuter-Lorenz et al. (1999) used measures of verbal working and long-term memory
to measure pre-frontal cortex activation in young and older adults. Cabeza et al.
demonstrated strong, localised, left-sided pre-frontal activation in the younger adults,
whilst the older adults displayed increased bilateralisation. This could of course, imply
that older adults are simply poorer at inhibiting activation in irrelevant areas, and are
gaining no benefit in performance from increased bilateralisation. However, Gutchess
et al. (2005) showed that increased activation of pre-frontal areas could serve as a
compensatory mechanism to medial-temporal decline in older adults. Participants demonstrated greater PFC activation if they also exhibited impaired para-hippocampal activation in a picture learning task. This may be a representation of the general change from posterior to anterior activation in cognitive ageing seen by Davis, Dennis, Daselaar, Fleck & Cabeza (2007). Increased frontal activation is a response to decreased ventral-visual and sensory activation. Salat, et al. (2004) found cortical thinning in frontal and occipital visual areas, this corresponds with Baltes and Lindenberger’s data suggesting a link between successful cognitive ageing and performance on cognitive tests relying on frontal components. It may also be an indicator of the need for increased frontal bilateralisation, and frontal activation in visual tasks as seen by Persson, Nyberg, Lind, Larsson, & Nilsson (2006). MacPherson, Phillips, & Della Sala (2002), demonstrated specific age-related differences in executive tasks associated with the DLPFC, but not in emotional tasks associated with the ventromedial prefrontal cortex. Initially this does not seem to support a hypothesis which suggests that older adults demonstrate increased recruitment of the DLPFC. However, MacPherson et al. did suggest that the decline in task performance may actually be representative of an increased, yet inefficient reliance on, and therefore activation of DLPFC areas in older adults.

Increased White Matter Hyperintensities (WMH’s) and deficient hippocampal activation are further candidates for functions aided by compensatory scaffolding. WMH’s have been found to be increased in visual areas in healthy cognitive ageing (Wen & Sachdev, 2004) and are candidates for the behavioural outcome of slower processing speed as they represent less efficient neural networks. Persson et al. (2006) demonstrated in a 10 year longitudinal study, that not only was decreased hippocampal volume associated with poorer memory performance, but that those who showed hippocampal activation also showed the greatest activation in the right pre-frontal cortex. Park and Reuter-Lorenz (2009) outline seven key tenets of STAC.

1.) “Scaffolding is a dynamic, ongoing property of an adaptive brain.”

The authors suggest that a reliance on secondary networks may be an important aspect of not only healthy cognitive ageing, but to successful learning and performance of new, complex tasks.
2.) “The Pre-frontal cortex is the primary locus for scaffolding.”

This is based on the data from Cabeza et al. (2004) and Perrson et al. (2006) already discussed within this section. It is posited that functionally specific areas such as the ventral-visual cortex are not likely to be able to provide scaffolding support, but are the areas that will benefit most greatly from it.

3.) “Scaffolding is a neurocognitive response to a challenge”

The challenges faced by the adaptive brain can be both intrinsic and extrinsic. The response of a young adult to an extrinsic challenge such as a difficult task may be the same as an older adult’s response to the intrinsic challenge of decreased storage capacity or processing speed. Banich (1998) demonstrated that younger adults demonstrated increased bilateralisation in a similar manner to older adults as a task increased in difficulty.

4.) “Scaffolding networks are less efficient than, honed networks.”

A network that has developed as a response to declines in other areas of performance will never be as efficient or precise as the structure that it is replacing.

5.) “The ageing brain is less efficient at generating new scaffolding. Pathology may entirely limit scaffolding operations.”

The ageing brain exhibits declining rates of neuroregeneration. As such any new scaffolding will be limited. Therefore, despite STAC being a theory of the changes in cognition with age, it does not suggest that scaffolding is the perfect solution to age-related declines.

6.) There is “Individual variability”, and there are varying “factors that promote scaffolding.”
There are multifactorial causes for ageing. Individuals may be susceptible to genetic or lifestyle risk factors that will lead to variation in the levels of decline seen

7.) “Scaffolding is promoted by training and cognitive activity.”

As with the concept of Hebbian learning, neurons that fire together, wire together. As such, the use of compensatory recruitment is likely to promote further compensation. This may be beneficial in maintaining performance in old age, or in the face of increasing task difficulty.

As can be seen, Park and Reuter-Lorenz present Scaffolding Theory as a healthy adaptive response to cognitive challenge. Whilst it has particular implications for research into cognitive ageing, it is not specifically a theory of ageing. In this respect it is similar to Stern’s cognitive reserve theory (2002). Stern suggested a response to brain damage may be the compensatory recruitment of neural structures not normally used for given tasks. However, unlike STAC, this was suggested as a response to an abnormal change in cognitive performance, not the healthy adaptive process suggested by Park and Reuter-Lorenz. It is suggested that the process of scaffolding using the prefrontal cortex is a direct response to decreases in parahippocampal volume and white matter integrity. Furthermore scaffolding does not represent arbitrary recruitment of ‘spare’ cognitive areas. Reuter-Lorenz et al. (2001) showed that storage areas could be supplemented by executive areas such as the PFC, but this was not a two-way system.

Park and Reuter-Lorenz’s theory is an interesting and persuasive argument, which corresponds with certain areas of the working memory literature. However, as a theory that is based, for the most part on the results of neuroimaging, rather than behavioural studies it currently provides more descriptive than explicative or predictive power to ageing research. A body of behavioural research identifying tasks that begin to rely on scaffolding with age, and those that don’t, as well as looking to identify the point in the lifespan that these changes can occur, would in conjunction with the suggestions
of STAC be of great benefit to the understanding of the mechanisms of cognitive ageing.

As with models of working memory it is obvious that there are competing and complementary methods of conducting cognitive ageing research, and interpretations of the data arising from this research. The introduction to both fields has attempted to highlight the key issues and theories that drive current research. However, both fields are too broad in scope and research output to fully consider within the remit of one thesis, therefore the next two sections of this review will focus on the variation of strategy and age-related variation in working memory task performance. Following an analysis of literature in these two fields the pertinent research questions to be explored in this thesis will be addressed.

Variation in Working Memory Performance

Whilst the first sections of this review have focused on models of working memory, there will now be a focus on variation within working memory performance. Variation is of course a vague term so there will be a focus on two key areas. Firstly, the process purity of memory tasks will be considered. Do short-term and working memory tasks actually measure performance of the specific cognitive mechanisms that they set out to? Is a verbal STM task measuring a specific capacity limited verbal store, or is it also assessing resources such as access to long term memories, or previous knowledge? Secondly, individual differences within working memory performance will be assessed. It is unlikely that all participants perform all tasks in the same manner as each other; it is also possible that people will not perform the same task in the same manner if they are asked to perform it more than once. Once a prior knowledge of task requirements has been acquired then it is likely that people will alter the strategies used to remember information. Empirical evidence and possible frameworks for both of these questions will be considered.
As previously discussed, the Multiple Component Model (MCM) (Baddeley & Hitch, 1974; developed in Baddeley, 1983; Baddeley, 1986; Baddeley, 2000; Logie, 2011) assumes separate capacity limited stores for visual and verbal information. The model also assumes a domain-general central executive involved in attention and the processing of more complex information. Later models also feature the episodic buffer which is postulated to be a domain general resource that allows for multi-dimensional representations of information, possibly based on prior long-term knowledge (Baddeley, 2000). The information held in the episodic buffer, has been suggested as being loosely analogous to what is posited to be held in the focus of attention of Cowan’s EPM (Baddeley, 2007, p155, Cowan, 2005, p 46-47 Engle et al, 1999). The use of selective interference tasks has demonstrated that, with regards to storage there is a dissociation of visual and verbal storage areas (Cocchini et al., 2002; Logie et al., 1990). A verbal interference task such as articulatory suppression will cause more disruption to a verbal memory task such as digit recall, compared to a visuospatial task such as visual patterns recall task with the opposite effect being found with visuospatial memory tasks. There is however, a large body of evidence suggesting that when there is availability for alternative methods of encoding, or the possibility of aiding memory performance with activated long-term memory information, then domain-specific tasks do become less domain-specific (Brown Forbes, & McConnell, 2006; Darling et al. 2010: Described below)

Within the verbal domain this has been demonstrated through the Spatial Numerical Association of Response Codes (SNARC) effect (Dehaene, Cohen, Sigman & Vinckier, 2005). The SNARC effect is based upon participants improved recall of digits when their presentation location matches their location on a mental number line. For instance, recall for lower value digits such as 1, 2 and 3 is improved when these numbers are presented at the left hand side of a stimulus. Recall for higher value digits such as 7, 8 and 9 is improved when they are presented on the right hand side of a stimulus. Dehaene and colleagues suggest that this represents an activation of long-term memory knowledge, or a visual representation of the arrangement of integers. Darling and colleagues (Darling et al., 2010, 2012) extended this research by
investigating a phenomenon that they termed visual bootstrapping. Visual bootstrapping of information was demonstrated by the benefit of prior spatial knowledge (in this case the layout of a telephone keypad) on the digit span of participants. Participants were tested on digit recall with presentation taking either the form of a typical number line, where numbers are read from left-to-right, or on a grid that represented the shape of a telephone keypad. In the telephone keypad condition numbers were either laid out as is seen on a traditional telephone keypad, or in a randomised pattern that would be unfamiliar to participants. Participants demonstrated greater recall in the familiar telephone keypad when compared to the other conditions. The absence of a benefit in the novel keypad condition suggests that this benefit is not simply down to the ability to create a spatial path in order to remember the sequence of numbers. This suggests that the improvement in recall is due to a familiarity with recall of numbers that are laid out in such a manner. This may be based upon long term knowledge of the motoric responses needed for such a keypad (Personal correspondence with Stephen Darling, August, 2014). Alternatively it may be that prior knowledge of telephone keypads, and the response required may lead to activation of the episodic buffer which helps to supplement verbal storage with a representation of prior knowledge during the task (Personal Correspondence with Stephen Darling, August 2014). Other work assessing multimodal or crossover effects in the verbal domain has suggested that distinguishability of information may be a factor. The previously mentioned work of Saito et al. (2008) demonstrated that phonological and visual similarity can negatively affect recall of Japanese Kanji letters, suggesting that there is a level of dual-coding in the processing of essentially verbal material. The authors also noted that there was a lack of interaction between the visual and phonological similarity effects, suggesting that this represented two systems being used, rather than a single multidimensional system.

There is a corresponding body of work that suggests a level of multimodal encoding, or long-term memory activation within the visual domain. Postle, Corkin, and D’Esposito (2005) demonstrated that verbal presentation of concrete items, such as jacket or table, lead to automatic activation of a visual representation, whereas abstract words such as jealous or ambiguous do not. Mate, Allen, and Bacques (2012)
demonstrated that the repetition of words which cause automatic visual representation will lead to a decrement in task performance on a visual task such as feature binding. Participants undertook a feature binding task in one of three interference conditions, repeating abstract words, concrete words, words that sounded like possible response stimuli or in a control condition performed in silence. Repeating abstract words had no more of an effect on visual memory performance than the control condition. However, repeating concrete words, or plausible response stimuli lead to a significant degradation in memory performance. Mate et al. suggested two possible explanations for such findings. Firstly it may be that repeating a concrete word activates a visual image from LTM and that this image interferes with the to-be-remembered information in a visual store. Alternatively the two representations may merge in the episodic buffer. The buffer may usually be recruited in order to supplement or maintain information held in the visual store, but the activation of a new item prevents this from occurring (Mate et al., 2012).

Further evidence for either the activation of long-term memory knowledge in the performance of visual memory tasks has been demonstrated in a series of studies by Brown and colleagues (Brown et al., 2006; Brown and Wesley, 2013). Easy and hard to label patterns sets were created using stimuli from the Della Sala et al. (1999) VPT. Participants in a pilot study were asked to provide verbal labels for stimuli sets from the task. Matrices that regularly received the same unique label, such as ‘duck’ or ‘the letter F’ (See Brown et al. 2006, for a full list) as opposed to ‘black and white squares’ or ‘some rectangles’ were placed in the easy-to-name (ETN) high verbal coding set, whilst those for which there were no names, or little agreement on names were placed in the hard-to-name (HTN) low verbal coding set. Brown et al. (2006) showed that individuals would consistently demonstrate higher visual spans when performing the VPT using the high verbal coding, as opposed to the low verbal coding stimuli. Brown and Wesley (2013) conducted a series of experiments using selective interference tasks and strategy questionnaires alongside the VPT in order to assess whether this benefit arose from a direct verbal recoding on the visually presented information using the phonological loop, via either an active multi-dimensional encoding strategy, or through activation of already held knowledge based on prototypical versions of the
shapes presented. In the first experiment participants were asked to carry out articulatory suppression during a maintenance phase between presentation and recall. There was an overall main effect of suppression with participants demonstrating lower overall scores in the suppression condition. However, there was no interaction between suppression and the pattern set being presented. This suggested that verbal recoding using the phonological loop is not the mechanism which leads to a benefit in performance in the ETN pattern set. The second experiment assessed the effect of a random spatial tapping task which was selected to interfere with any executive processes that may underlie the ETN benefit. The introduction of an executively demanding interference task led to a loss of the ETN set benefit. Participants were also asked to complete questionnaires assessing the methods by which they attempted to maintain memories the patterns presented. Participants were then divided into ‘Non-Combiners’, those who reported purely trying to recall the pattern seen, and ‘Combiners’, those who reported using a combination of strategies, such as naming shapes based on items, or objects they were already familiar with. When results were stratified by these groups it became clear that the greatest benefit to recall in the ETN set was for those who were ‘Non-Combiners’. However, those who were self-reported ‘Combiners’ demonstrated greater overall scores. Indicating that ‘Non-Combiners’ would only pursue verbal encoding when it was encouraged by suitable pattern sets. These results led the authors to suggest two things, firstly that the high verbal coding pattern set leads to an activation of some prior knowledge due to recognisability of the shapes presented and that there is some central executive cost to maintaining these representations prior to recall. Secondly, that not all participants are performing the VPT in the same manner, and that the manner in which the task is performed will affect the pattern of results displayed by any individual participant.

The data discussed in this section raise the possibility that whilst small amounts of information can be, and are held in domain specific stores such as are seen in the MCM model of Baddeley and Hitch (Baddeley & Hitch, 1974; Baddeley, 1983:1986; Logie, 2011), it is possible to supplement this storage through either multimodal encoding, or through prior knowledge (possibly activated from long term memory). When considering that any short-term memory system is required to store relevant recent
information, whilst helping the individual to form a narrative of the world around them. It is possible that the mechanisms of short-term memory have evolved to allow for ‘short cuts’ such as replacing memory for specific novel items, with an overall memory for previously encoded information which could provide an ample supplement for any new information. This is of course simply a short-term memory analogy of concepts such as Bartlett’s Schema theory (1932) and gives an idea, but not a full explanation of why, and at what point in short-term memory storage does a task also become a measure of long-term memory activation and multi-modal encoding.

The studies discussed so far have all been what can broadly be described as ‘simple span’ tasks. That is, participants are given information to remember and up to a point, either through storage, verbal rehearsal in the phonological loop, or spatial rehearsal using the inner scribe the individual can perform the task sufficiently. However ‘Complex Span’ tasks such as the Working Memory span task (WM span) of Daneman and Carpenter (1980) (See also Baddeley, Logie, Nimmo-Smith, & Brereton, 1985; Duff & Logie, 2001) require participants to process, information whilst also maintaining target information for subsequent recall. In the typical WM span task participants are asked to read a list of sentences whilst deciding on their veracity. After presentation of sentences the participants are required to recall the last word of each sentence. This, of course presents a very different task than simply being asked to recall a list of words. At face value it appears to provide a more realistic measure of the processes of memory that are met in everyday life, and it has been found to correlate with fluid intelligence (Baddeley et al., 1985, Kane & Engle, 2002).

Individual differences in working memory performance

The individual differences (ID) approach to cognitive performance typically involves testing participants on a variety of tasks and using techniques such as factor analysis to demonstrate how performance on certain tasks can be clustered together (Baddeley, 2007. p179) (See Deary, 2001 for an introduction; Deary, 1993 for an example). Whilst methods such as this are useful for describing which tasks rely on similar abilities, they
do not allow the identification of the specific mechanisms through which individual
tasks are performed. Mackintosh (1998) states that techniques such as factor analysis
do little other than describe the relationship between various IQ tests and cannot reveal
the structures that underlie human ability. Baddeley (2007, p176) notes that there has
been less success in generating a theoretical groundwork for high and low performance
in intelligence testing using the psychometric approach. Whilst this may be a strong
view to take when assessing the successes of correlational work assessing risk factors
for cognitive ageing, such as a lack of exercise, or excessive alcohol consumption
(Batty et al., 2008; Gow, Mortensen, & Avlund, 2012), it is a valid point when
considering the intricacies of various working memory models that have been
discussed in this chapter. This section shall consider IDs in working memory
performance and what this means for the understanding, and the reconciliation of the
various working memory models.

Engle and colleagues (Engle et al., 1999; Kane & Engle, 2002; Unsworth & Engle,
2006; 2007a; 2007b), through the use of large study samples, complex span tasks, and
structural equation modelling have combined the experimental and correlational
approach to provide an interesting description of the possible processes underlying IDs
in working memory. Performance is measured on tasks such as Daneman and
Carpenter’s (1980) WM span task, as well as further developed versions such as the
Operation Span (Ospan) task (Turner & Engle, 1989) which also require a level of
processing in assessing the validity of the presented information, are measured.
(Operation span tasks work on the same principles as WM span tasks but with small
mathematical equations followed by an unrelated word to remember as opposed to
sentences). Performance on tasks such as these is assessed in relation to performance
on simple span tasks and tasks that are designed to measure Gf (Fluid intelligence),
such as Cattell’s Culture fair test and scholastic aptitude tests. Modelling techniques
are used to assess the relation between simple and complex span tasks (Engle et al.,
1999). From this, inferences can be made about the way in which these tasks are
performed. Furthermore the comparison of errors made between tasks (Unsworth &
Engle, 2007a) can give information as to how tasks are being performed. Rosen and
Engle (1997) demonstrated that participants with higher-spans in complex span tasks actually demonstrated a greater negative dual-task effect that those with lower spans. This suggested that those who were able to achieve higher spans were directing some form of executive resource towards the performance of memory tasks, and that this ability was not available under selective interference conditions. Baddeley (2007, p186) suggested that this may in fact be an indication of lower motivation in the lower-span participants, rather than demonstrating a greater ability in high span participants, and that selecting different groups is likely to exacerbate any difference in strategy use. What is clear though is that the mechanism by which high and low span participants perform a task is not necessarily always the same.

There are inherent difficulties in measuring what is ‘executive task’ as strategy use can vary between participants, and this flexibility is the essence of the working memory system (Baddeley, 2007, p126). The same person may not perform the same working memory task in the same manner over a repeated number of trials, so it is hard to define at what point the move between storage and executive processing task occurs. Furthermore it is hard to avoid measuring motivation, rather than ability in task performance when assessing for high and low spans. However, it still provides a dichotomy in task performance that allows for an assessment of the difference in task performance methods. It is clear to see that to understand IDs in methods of performance we need to understand the short term/working memory or simple_complex span task distinction. Engle et al. (1999) attempted to clarify this distinction by assessing performance on tasks considered to be measures of complex span, such as the WM span task and Ospan, tasks considered to be simple_short term memory tasks such as word span, and two tests of general fluid intelligence (Verbal and Quantitative Scholastic Aptitude tests). Using structural equation modelling they demonstrated that ability in short-term and working memory tasks represent distinct but highly related constructs. However, only working memory/complex tasks reflected a shared variance with measures of fluid intelligence. This led Engle et al. to argue that both intelligence measures and complex span tasks measure an ability to maintain a representation whilst attending to other information, whereas the relation between simple and complex span tasks may reflect the necessity for storage in such tasks.
Engle et al. highlight that within this definition, that what is a simple/short-term memory task for some individuals may actually represent a complex/working memory task in others. Those who, through luck or design have a greater simple storage capacity may find that the threshold for a simple span task becoming a more complex task is much higher than for those who do not. These results and suggestions are framed within the cognitive models of Baddeley (1986; 2000), and Cowan (2005). Short-term memory as a limited capacity store of information is analogous to the stores of the MCM, but is also seen as commensurate with Cowan’s decay of information over time. The entrance into ‘working memory’ as measured by complex span tasks which require storage of old, and attention to new information may represent Cowan’s focus of attention, Baddeley and Hitch’s central executive, or possibly the episodic buffer of later versions of the MCM (Baddeley, 2000). The IDs lie within the ability to control attention towards relevant task goals. Although later work has specified that IDs in working memory can be ascribed to the amount of information that can be held in primary memory, and the ability to take relevant information from secondary memory (Unsworth & Engle, 2007b). However, both of these explanations suggest that IDs arise from the interplay of short-term storage and higher-order attention related functions.

In order to further understand how IDs affect the mechanisms at work in task performance, Unsworth and Engle (2007a) assessed data from various papers (Maylor, Vousden, & Brown, 1999; Kane & Engle, 2004; Unsworth & Engle, 2006) assessing the types of errors and interference seen in both simple, and complex tasks, that are verbally based (Rspan, Ospan, Digit Span, etc.). As would be expected there are some similarities and some differences between the tasks. Typically complex tasks showed more item errors (where incorrect items are recalled), whereas simple span tasks show more order errors (where the correct information is recalled, but in the wrong serial order) (Unsworth & Engle, 2007a). This would suggest that the incorrect answers in complex span tasks come from a loss of to be remembered information due to the intervening sentences/mathematical problems, whereas incorrect answers in the simple span task may be due to errors in rehearsal which lead to an incorrect order of recall. Furthermore simple span tasks demonstrate smaller recency effects compared to
complex span tasks. Despite these differences in performance, both complex and simple span task show effects that imply a reliance on some form of verbal rehearsal. Both forms of tasks show lower scores for recall when participants are asked to perform articulatory suppression during maintenance, they also both appear susceptible to the word length and list length effect (Unsworth & Engle, 2007a, using data from La Pointe & Engle, 1990). These are both forms of interference effects which suggest a decline in performance due to the increased time taken to rehearse longer words or longer strings of information. Rather unsurprisingly, given the definition of the two types of task it was found that the total n. of recall is typically higher in simple than in complex span tasks and any effect based on rehearsal is typically stronger in simple compared to complex tasks.

As with Engle et al. (1999), Unsworth and Engle (2007a) found that complex span performance is more closely related to abilities on measures of general intelligence than simple span performance. Although it was found higher performance on simple span tasks was related to greater fluid intelligence, and at the highest level reflected a similar amount of shared variance as is seen between complex span and fluid intelligence. This is not reflected by a similar change in the relationship between complex span and fluid intelligence tasks. Engle et al. (1999) suggested that the mechanisms used to conduct complex span tasks, may also be at use in allowing participants to maintain higher spans in simple span tasks, providing partial agreement with Tehan, Hendry and Kocinski (2001, p346) who stated that “When it comes to performance on simple and complex span tasks, the data clearly indicate that both tasks are supported by a common storage system…”. Whilst the data do clearly indicate a shared performance system, it is possible that the amount that can be stored in this will differ between individuals. Two words that represent two discrete items of information for one participant could possibly represent a single chunked item for another. An ability to chunk items, or to control attention between a set of chunked, to-be-remembered items, and newly presented information may represent the abilities needed to perform complex, and high-load versions of simple span tasks. As previously discussed, a system of memory where to-be-remembered information is initially held in PM, or a domain specific simple store, but subsequently held in SM,
or the episodic buffer through semantic associations, prior knowledge or mnemonics may be able to explain factors such as individual differences in task performance, as well as the changing relations between tasks and general intelligence measures. Baddeley (2007, p 186) highlights that by selecting for high and low span participants and analysing differences in performance, that researchers are artificially engineering a difference in the methods by which individuals perform tasks, and as such increasing the likelihood of finding such differences. Whilst this is a valid point, it does not explain how or why these differences arise, and by identifying individual differences at either end of the spectrum of performance we will develop a more nuanced understanding of the underlying mechanisms at work.

Evidence for differential methods of task performance away from those in high/low performance categories has been demonstrated by Logie, Della Sala, Laiacona, Chalmers, and Wynn (1996). Using 251 participants Logie et al. first demonstrated reliable word-length and phonological similarity effects in both visually and auditorily presented immediate verbal serial order recall tasks. Despite there being large group effects, 43% of participants failed to show at least one of the effects. A lack of effect was correlated with lower overall task performance, suggesting that the rehearsal mechanisms employed to improve performance, which are affected by word length and phonological similarity may not be employed by those with lower performance. A follow-up experiment retested 40 of the original participants, half of whom had failed to show either a word-length or phonological similarity effect in the first experiment. There was little reliability between showing an effect at the time of the original test, compared to the second testing period. Furthermore the effects seen in task performance correlated with reported strategies. The strongest effects of word-length and phonological similarity were found in those who reported performing the task using simple verbal strategies such as rehearsal. Those who used strategies such as using semantic structures, visual codes, or first letter acronyms showed weaker effects. However, these changes in performance effect were not reflected in overall span performance. This Logie et al. paper provides compelling evidence for differences not just in performance methods between individuals, but in the performance method of each individual at different times.
It is clear from assessing variation in working memory performance that there are distinct IDs in task performance, and that people perform different tasks differently, at different times, depending on the available resources within task presentation, and their own prior knowledge. However, this does not make for an especially robust or easy experimental paradigm to assess. What we can say is that there is a separable ability for storage and processing (Duff & Logie, 2001; Unsworth & Engle, 2007b) and within this storage area, we can further divide into visual and verbal domains for simple to-be-remembered information (Baddeley, 1983; 1986, Logie et al., 1990). Processing and the allocation of attention can be considered to be the domains of the central executive (Baddeley, 1996). Outside of the MCM this can be considered as the focus of attention (Cowan, 2005). Previously held knowledge, or chunked versions of new information are posited to be held in activated long-term memory and attended to by the focus of attention in Cowan’s model, and this can be seen as having similar qualities to the episodic buffer in the MCM (Baddeley, 2007 p155; Cowan, 2005; p46-48). However, this is with the caveat that Allen, Baddeley, & Hitch (2006) demonstrated that the storage of bound information within the episodic buffer did not require explicit attention.

Whilst the definitions and descriptions of the architecture of working memory are of course, imperative for the direction of new research, it is perhaps best to look to Logie (2011) who argued that whilst working memory is of course one system, with many separable components, with definite structures within the memory system, the extent to which these are used in each individual task are modulated by a myriad of factors. These include motivation, prior task knowledge, and simple storage abilities. This is commensurate with the view that will be taken in this thesis where attempts will be made to understand the mechanisms by which individuals perform tasks, rather than looking to the specific mechanisms that tasks measure. This may seem like an arbitrary distinction, but it is one based on the common sense view that individuals will try and draw on previous knowledge to complete a task in an experimental environment, if they believe, as many participants do, that the experimenter wishes them to perform to the absolute peak of their ability. In order to perform tasks to their maximum ability it
is of course likely that some individuals will seek to maximise storage of information through verbal rehearsal of the presented information, whilst some may choose to tie information presented to items that are familiar from their everyday lives. In such a case a simple VPT presentation may represent a simple storage and rehearsal task for the first participant, a ‘chunking effectiveness’ task for the second participant, and a semantic association task for the third. The work of Brown et al. (2006; 2013) and Darling et al. (2010; 2012) shows that visual or verbal storage tasks are not always process pure. Domain specific storage, and domain general encoding/maintenance are recruited in order to supplement task performance. This view allows for an understanding of the MCM that is in line with the concept of primary/secondary storage outlined by Unsworth and Engle (2006) and of the Embedded Processes Model outlined by Cowan (2005).

**Age-Related variation in Working Memory Performance**

The current section will explore the variation in working memory performance that can be attributed to changes in behavioural or neuronal systems with age. The initial focus will be on the increasing generalizability of task performance and activation patterns in healthy adult ageing (Cabeza, Anderson, Locantore, & McIntosh, 2002). The concept of dedifferentiation will be explored through both imaging studies and experimental manipulations, as well as the possibility that overall behavioural patterns can mask not only underlying changes in strategy use, but compensatory neural recruitment. The issue of domain-specific decline and individual differences in healthy adult ageing will then be considered. Does the variation seen between younger adults in working memory performance (outlined in the above section) increase in old age? If working memory performance is based on activated long term memory, as assumed by the Cowan model (1988, 1995, 2005), then there may be, with increasing age, a greater reliance on previously held knowledge, rather than processing of new information to complete working memory tasks. It is also feasible that there will be interference from previous knowledge due to inefficient application of strategies
which rely on prior knowledge, rather than outright issues in short-term memory storage (Hedden & Park, 2001).

Dedifferentiation in Cognitive Ageing

A pervasive theory regarding cognitive ageing is that of increasing generalizability of processing resources with age (Johnson et al., 2010). This dedifferentiation refers to the process where distinct pools of processing resources in young adulthood develop into a single more general resource with increasing age (Park et al., 2002). There is in essence logicality to this theory which sees an increasing specialisation of resources and acquiring of task abilities in the developmental literature (Pickering et al., 2001; Pearson & Logie, 1997), coupled with a decline in specialisation with increasing age. But whilst the concept of dedifferentiation, or increasing generalizability is supported by a wealth of data (Li & Lindenberger, 1999; Hartley, Speer, Jonides, Reuter-Lorenz, & Smith, 2001), there is evidence to suggest that older adults are not simply reverting to the methods of performance seen in children, but demonstrating increased activation in frontal areas associated with executive control (Reuter-Lorenz, Jonides, Smith, Hartley, Miller, & Marshuetz. 2000). It is unclear as to whether this increased activation represents some form of compensatory recruitment, or is indicative of a decreased ability to inhibit activation.

It is principally performance within memory tasks that are commonly taken to measure visuospatial ability that demonstrate greater reliance on general processes with increased age (See Johnson et al. 2010 for an example using a large cross sectional data set). Chen, Myerson, & Hale (2002) compared the performance of older adults on seven measures of visuospatial ability. Three were measures of memory for static visual imagery, items that biologically are maintained in the ventral stream, or in the architecture of the MCM are likely to be stored in the visual cache. Four were measures of memory for movement and location; these are taken to be held in the dorsal stream, or rehearsed by the inner scribe (Logie, 1995, for a multiple component view; Ungerleider, Courtney, & Haxby, 1998, for a neuroimaging view). Furthermore,
ventral regions are taken to be passive-storage units, whereas dorsal regions are more commonly activated during the maintenance and manipulation of to-be-remembered information (D’Esposito, Postle, Ballard & Lease, 1999). This corresponds with the distinction between storage only, short-term memory, and processing plus storage, working memory tasks outlined by Engle et al. (1999). It is also commensurate with the later findings of Rudkin et al. (2007), who found that a sequential visuospatial task that required rehearsal through the inner scribe was more susceptible to interference from an executive random generation task, than a static visuospatial task which required the participant to maintain memory for a static image. Using principle components analysis Chen et al. (2002) found that whilst a two-factor structure comprising of a general resource factor, and a bipolar visual/spatial factor was the best fit for younger adults’ data, data for the older group was best fit by a one-factor solution. Furthermore the correlations between tasks within the same processing stream were far stronger in younger adults than they were in the older group. Chen et al. speculated that this reliance on a general processing factor may be behavioural evidence for the increased frontal, and bilateral activation seen in older adults compared to younger adults in Li & Lindenberger (1999). It was also considered that this increase in activation reflects the acquisition of compensatory cognitive and behavioural strategies in order to maintain or improve task performance.

Hartley et al. (2001) have provided evidence for a possible strategy use in the face of visuospatial dedifferentiation in older adults. Memory for verbal information, object naming, and spatial location was assessed. In line with the MCM there was a dissociation between all three abilities in younger adults, and in line with the suggestions of Logie (2011) and Logie et al. (2015) there was an involvement of verbal ability in the object naming task in both age groups. However, the older group also demonstrated a relationship between verbal ability and memory for spatial locations. Hartley et al. presented two possible, and plausible explanations, that were similar to the concepts later put forward by Chen et al. (2002) and represent two common arguments put forward to explain any later-life dedifferentiation. Firstly they suggested that the specific strategy use in older adults may be an attempt to use mnemonic aids in order to complete spatial tasks. A second explanation is that older
adults are unable to inhibit the activation of verbal working memory, even when this may not be of benefit to task performance. Both of these explanations would fit with the patterns of activation seen in Reuter-Lorenz et al. (2000) where it was shown that in younger adults’ activation for verbal tasks was predominantly left-lateralised and activation for spatial tasks was predominantly right-lateralised, in posterior areas. However, during performance on a verbal, and a spatial 3-second storage task, older adults demonstrated increased bilateral activation for both types of memory tasks, more specifically there was an increase in sub-regions associated with rehearsal, as well as paradoxical laterality, with spatial tasks also showing left hand activation, and vice-versa for verbal tasks. Reuter-Lorenz et al. (2000) speculated that rather than being an inhibition deficit that is a product of neural decline, this could be representative of compensatory neural recruitment in response to the difficulty of the task.

Within an EPM view it could be argued that the ageing behaviour seen in Chen et al. (2002) and Reuter-Lorenz et al. (2000) simply represents a changing of the focus of attention, in older adults towards previously held knowledge about how to conduct a task, rather than a complete focus on what is to be remembered. In the multiple component view this could be reconciled as the use of the episodic buffer to help provide a prototypical version of the information that is to be remembered. However these are speculative views and do not take into account data which suggest that, rather than a dedifferentiation of abilities across the lifespan, separate resource pools remain separate, but all decline due to overarching factors such as decline in processing speed (Salthouse, 2000), or an overall neuronal decline with age (Maylor et al. 1999). Maylor et al. found that the patterns of performance seen between young and older adults on two serial-order recall (one verbal, one spatial) tasks were matched in terms of errors such as omissions, intrusions, and order errors. This is damaging to any theory suggesting that there are qualitative behavioural differences in the way young and older adults perform different types of memory tasks. Maylor et al. suggest that the declines in the data of older adults were best described in terms of frontal decline, and a general response slowing. Whilst Maylor et al. do not suggest any qualitative difference, it is worth noting that the matching patterns of performance in visual and
verbal serial-order recall tasks, which are likely to have a large rehearsal element, are actually consistent with the results of the Reuter-Lorenz et al. (2000) PET study previously discussed.

Park et al. (2002) assessed visual and verbal memory across the adult lifespan on a series of processing speed, sensory functioning, short-term, working, visuospatial long term and verbal long term memory tasks. They found that processing intensive tasks, regardless of visual or verbal domain showed accelerated decline compared to short-term measures of pure storage. Within short-term storage measures there was a slight differential decline with visual tasks showing a greater effect of age than verbal tasks, this is in line with the findings of Logie & Maylor (2009), and Johnson et al. (2010). It is also consistent with the separation of processing and storage abilities seen by Duff & Logie (2001). Crucially, however, Park et al. did not find behavioural evidence for a dedifferentiation of visual and verbal resources across the lifespan. However, as this was not a selective interference study, it is difficult to infer the methods by which participants achieved their own maximal task performance. Hartley et al. (2001) suggested that selective interference methods were the optimal method for assessing phenomena such as dedifferentiation as they allow assumptions to be made regarding the exact mechanisms at work. As such, Park et al. (2002) could suggest that whilst there was no behavioural difference in patterns of overall task performance, this may be due to compensatory neural recruitment such as that seen in Reuter-Lorenz et al. (2000) and Park et al. (2001). The pattern of data seen by Park et al. also reiterated the blanket decline of processing speed, as predicted by Salthouse (1996) as a factor in cognitive ageing. It was suggested that this was due to an overall decline in neuronal integrity with increasing age.

What then can be taken as a framework for cognitive ageing upon which to base this thesis? Is the decline in cognitive ageing due to a lack of inhibition of frontal areas (Hasher and Zacks, 1988), general cognitive slowing (Salthouse, 1996; 2000), or a specific dorsolateral frontal decline? (See Phillips & Della Sala, 1998) Beyond the cause of the decline, what is the nature of this change? There appears to be dedifferentiation in cognitive architecture (Reuter-Lorenz et al., 2000; Chen et al.,
2002), but its appearance at the behavioural level appears dependent on the use of tasks (Chen et al., 2002; Park et al., 2002; Johnson et al., 2010). To return to the analogy between physical and cognitive age related decline seen in the introduction, it is possible that the patterns of performance seen in older adults during cognitive tasks would be similar to the change in muscular mechanisms needed to lift a heavy item with age. In a younger adult’s fully functioning system a heavy item can be lifted with the specific muscles needed to move the arms. However, with increasing age, and a decrease in muscle mass, the power of the biceps alone may not be enough to lift the item. It would be sensible to employ other sets of muscles such as the quadriceps to allow the legs to be used in conjunction with the arms. This would be an example of compensatory recruitment. It is not a lack of inhibition, but nor is it a conscious strategy use, the overall outcome of a ‘lifted box’ will be the same, but the method of achieving it will be slightly different. Furthermore, it may not always be the optimum strategy as it may be to the detriment of other aspects of the lower limbs. The compensatory recruitment of cognitive resources may follow a similar pattern. Increased activation may not necessarily be a result of a well-chosen strategy, but simply an automatic response. There is still an overall single-component of ‘ageing’, which may be characterised by declining processing speed, but within that single component the mechanisms that add up to it may behave differently.

The analogy above has parallels with the Scaffolding Theory of Aging and Cognition (STAC) of Park and Reuter-Lorenz (2009) that was discussed earlier in this chapter. This theoretical model attempts to integrate data suggesting an overall decline in structural integrity and processing speed (Maylor et al., 1999; Salthouse, 1996; 2000) with behavioural and neuronal evidence for dedifferentiation, specifically of visual abilities, with age (Chen et al., 2002; Park et al., 2000, Johnson et al., 2010). The hypothesis being that the compensatory recruitment seen in older adults is an automatic process that is seen across the lifespan, but is more prevalent in older adults due to the decline in overall task ability with age. It also suggests that compensatory recruitment would not normally allow an individual to perform above the original level of cognitive performance, but rather will allow performance to be maintained. The decline in task performance (Johnson et al., 2010; Myerson, Hale, Rhees & Jenkins,
1999) seems to be attenuated by an increased reliance on general abilities and/or rehearsal mechanisms (Hartley et al., 2001). Scaffolding theory would suggest this is due to adaptive compensatory recruitment, which at the neuronal level is characterised by increased bilateral frontal activation, and at the behavioural level would be associated with increased executive function. This adaptive recruitment may be an automatic response to increasing task difficulty (Park & Reuter-Lorenz, 2009), and will form the basis for hypotheses of age-related decline within this thesis. The next section will focus on which tasks show greater decline, and what abilities are protected with age in order to understand the mechanisms by which older adults may achieve overall task performance.

Variation in working memory tasks with age

A common finding within the cognitive ageing literature is that of differential decline between visual and verbal memory abilities with age. Park et al. (2002), Johnson et al. (2010), and Myerson et al. (1999) all demonstrated a faster decline in visual working memory task abilities compared to verbal task abilities. Johnson et al. showed that verbal task ability plateaued at around 20 years of age and remained at a similar level in separate 5 year age groups until around the age of 65, whilst visual task ability started to decline towards individuals’ late 20s and by the age of 40, was roughly equivalent to that of a 10 year old. What though, are the factors that lead to this decline? The first half of this section outlined the dedifferentiation of cognitive abilities with age. This section will focus on specific task abilities and consider particular task abilities that do not decline with age. Is it possible to infer changes in the mechanisms used to perform tasks with old age based on either individual differences or preserved task abilities across the lifespan? In the introduction to this review, the concept of the dull hypothesis (Perfect & Maylor, 2000) was discussed, and with it the need to understand the varying trajectories of age-related performance. This section will attempt to cover these issues.

As introduced earlier in this chapter, the study of individual differences typically involves assessing correlations between task abilities and assessing the change in
correlation based on external factors such as lifestyle, or internal factors such as genetic make-up (See Batty et al., 2008, for an example). This approach has the benefit of often assessing large numbers of individuals across a broad range of factors in order to provide an overall picture of the effects of ageing. Wilson et al. (2002) assessed 694 individuals, with a mean age of 76 at the initial study point, over a 6 year period on measures of story retention, word retention, word generation, word knowledge, digit span, perceptual speed and visuospatial ability. Overall task decline was generally faster in those who had been older at the start of the study. Most interestingly, there were large individual differences in the rates of decline, and performance in the first phase of the study was not a significant predictor of decline. Furthermore there were differential trajectories of task related decline at the level of the individual.

In a series of studies assessing the Lothian Birth Cohort, Deary and colleagues (For a review see Deary, Whalley & Starr, 2009) have found that childhood mental ability (measured at age 11) is associated with a number of factors including general health as well as cognitive decline. Furthermore, maintenance of healthy lifestyle factors, including, but not limited to low alcohol consumption and non-smoking are associated with later life cognitive benefits. Whilst these studies provide useful information regarding the overall concept of cognitive ageing, they have the drawback of an overall cognitive performance being derived from a series of tests geared towards providing a single score. Whilst it is possible to see if cognitive ability goes ‘up’ or ‘down’ in association with external factors, it is not possible to understand the mechanisms that are fundamental in the change of performance. That is not to say that studies with a correlational design cannot assess the differences between very specific abilities if designed in such a manner. Brown, Brockmole, Gow, & Deary (2012) measured older adults with a mean age of 73 on measures of processing speed, executive function, spatial working memory and verbal fluency to assess predictors of visual working memory performance. It was found that processing speed and executive measures were the strongest predictors of visual working memory performance.

Although it is possible to assess separate abilities using a correlational design, there is a large body of work that favours the dual-task, or selective interference approach to
the assessment of older adult task performance. Typically participants are presented
with a primary memory task, coupled with a secondary interference task to be
performed at the encoding, maintenance or retrieval stage of the primary task (See
Logie et al., 1990; Cocchini et al., 2002). In studies of ageing, where the aim is to
assess the relative decline of certain task abilities in others, and to isolate these specific
abilities, the use of the double dissociation approach can provide a stronger test of
separability than by simply assessing each task and gauging the relative decline. If
memory systems do become interdependent or generalised with age then the use of
domain-specific selective interference tasks will provide a clearer picture of the
mechanisms being used to attain maximal task performance. In short, the double-
dissociation method allows the experimenter to test what a test is actually assessing,
rather than assuming it is measuring a specific construct (Hartley et al., 2001; Logie et
effects of an interference task on older adults, compared to younger adults in a task of
associative binding. The performance of both groups improved with increased
presentation time. However the older adults required a significantly longer increase in
presentation time in order to demonstrate increased ability. It is also possible to
introduce a secondary task to provide a beneficial effect on task performance. Fox and
Charness (2010) found that the requirement to verbalise processes during the
performance of Raven’s Progressive Matrices improved the performance of older, but
not younger adults. Together these two examples begin to demonstrate that not only is
visual task performance slower to improve in older adults, but it also benefits
differentially from additive strategies, suggesting that the mechanisms by which older
adults perform tasks may be qualitatively different from the methods used by younger
adults.

There is an extensive literature assessing and comparing dual-task performance
between young and older adults. Within the tenets of the MCM an individual should
be able to carry out more than one memory task with little detriment to either, so long
as both tasks are intended to tap a different component of the working memory
architecture. For example, there should be less of a decline in performance on a verbal
working memory task if a spatial tapping task is carried out during a retention interval,
or during retrieval of information, compared to the decline that would be seen in a visual task with the same interference (Logie et al., 1990; Cocchini et al. 2002). In a series of studies Logie and colleagues (Della Sala, Cocchini, Logie, & MacPherson, 2010; Logie et al., 2004; Logie, Della Sala, MacPherson & Cooper, 2007) using predominantly serial order verbal recall and spatial processing tasks have demonstrated that efficient dual-tasking is possible in both young and older adults, as long the requirements of the task are titrated to the single-task ability of the individual (see Logie et al., 2015 for a review). It was also found that those with Alzheimer’s disease were unable to demonstrate efficient dual-tasking even after titration (Logie et al. 2004), suggesting that there is a specific executive capability to perform two tasks at once, and that this does not appear to be impaired in healthy adult ageing.

However, there are some discrepancies within the dual-tasking literature which suggest that, whilst older adults are capable of producing an overall dual-task performance in the manner of younger adults, the methods by which they attain this performance may differ. Göthe, Kliegl, and Oberauer (2007) assessed dual-tasking performance between young and older adults as function of the time taken to complete two tasks. Parallel processing was said to be achieved once individuals were able to complete a dual-task paradigm with the same response latency that they had performed in a single-task condition. Whilst there was no age effect on accuracy in the dual-task condition, none of the older adults were able to achieve the threshold for parallel processing, compared to 75% of the younger adults. Logie et al. (2007) found that whilst there was no effect on memory performance when performing a speeded secondary task at retrieval, performance of a speeded task at encoding led to a significant slowing in secondary task performance in older adults. This decline in secondary task performance at retrieval has also been demonstrated by Naveh-Benjamin, Craik, Guez, & Kreuger (2005). It is possible that older adults show deficits in performance of secondary tasks when under time constraints due to the reliance on more general resources with age (Reuter-Lorenz et al., 2000; Johnson et al., 2010). This reliance on general resources may require the older adults to attempt to switch between the two tasks rather than perform dual-tasking in the purest form. Alternatively, this decrease in performance may represent a decline in the ability to
switch the focus of attention, or executive resources; as such information may be stored, but difficult to retrieve due to attention being directed elsewhere.

A further discrepancy within the dual-task literature can be found regarding the nature of the memory tasks presented to participants. Studies such as those conducted by Logie and colleagues commonly use storage/rehearsal only tasks such as serial order digit recall. However other studies such as Naveh-Benjamin et al. (2005) use free recall tasks which may be open to the use of semantic encoding. Tasks such as those used by Naveh-Benjamin et al. tend to produce greater discrepancies between the performance of young and older adults compared to the storage only tasks seen in the Logie et al. studies. Park et al. (2002) demonstrated a greater decline in processing based memory tasks that may rely on semantic encoding, compared to short-term storage tasks in older adults. Furthermore, Logie et al. (2015) highlight the relative age insensitivity of tasks, such as immediate verbal recall, that rely on task specific variance that was seen in Johnson et al. (2010), compared to tasks that rely on more general abilities with age. It is possible that discrepancies in dual-task performance with age essentially become measures of the amount of general processing, or the interplay between pure storage and processing related tasks. This is a hypothesis that would be commensurate with both the MCM (Baddeley, 2000, Baddeley, 2007, Logie, 2011) and the EPM (Cowan, 2005).

The dual-task literature suggests that there are qualitative differences in the manner that young and older adults approach short-term and working memory tasks. Whilst overall task performance can show similar patterns (allowing for some age-related decline), the effects of secondary and interference tasks suggest that older adults may be performing tasks in a manner akin to that described by Scaffolding Theory (Park & Reuter-Lorenz, 2009). That is, that general resources are recruited (possibly through conscious recruitment, or through a decline in inhibitory ability) in response to an extrinsic challenge such as task difficulty. Overall it appears that within cognitive ageing that, at the level of the whole person there are changes in performance compared to younger adults that are affected by various lifestyle and genetic factors (Wilson et al., 2002; Deary et al., 2012). In separate subsystems whilst the initial
performance remains similar, there are differences in the way tasks are performed, and that these could be construed as a dedifferentiation in old age (Chen et al., 2002; Johnson et al., 2010) The experimental literature suggests that older adults are not just poorly performing versions of younger adults (Jost, Bryck, Vogel, & Mayr, 2011) and there is an, albeit possibly unconscious, qualitative change in the manner of task performance in older adults. It is not clear if these changes are based on an inability to inhibit frontal activation, a decline in visuospatial storage capabilities, an active compensatory recruitment or a combination of all three. Exploring the manner of this change and the situations in which differential task performance occurs will form the basis for the research conducted within this thesis.

Development of Rationale

1) The introduction to this chapter highlighted the need to reject the ‘dull hypothesis’ (Perfect & Maylor, 2000). It is clear that little progress will be made in the field of cognitive ageing if studies are designed simply to highlight an overall decline in task performance in older adults compared to their younger counterparts. Approaches to cognitive ageing research were considered. The psychometric approach is useful in identifying the changes between task abilities and the effects of lifestyle factors across the lifespan (Deary et al., 2012), whereas the experimental approach is useful in identifying specific changes in task performance through selective interference tasks.

2) Three major models of working memory were then considered, the Multiple Component Model (Baddeley & Hitch, 1974; Baddeley, 1983; 1986; 2000; Logie, 2011), the Embedded Processes Model (Cowan, 1988; 2005) and the system of Primary and Secondary Memory (Engle et al. 1999; Unsworth & Engle, 2006). There are differences in emphasis and research question between the models. It is broadly agreed that task performance is directed by a focusing of attention towards a given stimulus. It is also agreed that whilst working memory is primarily a system of short-term memory and processing, there is
an interplay with long-term memory that can sustain and improve working memory representations. Whilst the proponents of the Multiple Component Model have demonstrated domain-specific stores within the memory system, it is also agreed that these systems can all work in concert thereby forming one working memory system with many sub-components (Logie, 2011). These sub-components can be differentially recruited depending on variables such as task difficulty, individual ability (Rosen & Engle, 1997) possibly with increasing age.

3) Three major models of cognitive decline were considered. The Inhibition Deficit hypothesis (Hasher & Zacks, 1988), the Processing Speed Theory of Decline (Salthouse, 1996, 2000) and the Scaffolding Theory of Age & Cognition (Park & Reuter-Lorenz, 2009). The first two focus on a specific aspect as the catalyst for age-related decline in cognitive performance. Whilst it is evident that there are specific deficits in processing speed and inhibitory circuits with age, for the research within this thesis the performance of older adults is perhaps best framed within the tenets of Scaffolding Theory. This accepts the general decline of old age, but also describes the changes in the biological system as the brain attempts to attenuate these changes through compensatory recruitment, particularly bilaterally in posterior storage areas, and in the dorso-lateral pre-frontal cortex. What is not clear from this theory is if compensatory recruitment is an active response to consciously maintain performance, or a passive reaction that is the either the result of declining ability in task specific stores, or evidence of a lack of activation inhibition.

4) Variation in working memory task performance was considered. Initially the concept of process purity was discussed. Evidence from both visual and verbal working memory tasks suggests that, where possible participants will supplement performance through either cross-modal encoding, or activation of long-term memory representations, possibly in the episodic buffer (Brown et al., 2006; Darling et al., 2012). Individual differences in working memory performance were then considered. It is apparent that specific working memory tasks are not always measuring the same ability in each individual. What may
5) The final section examined variation in working memory task performance that was specific to ageing. It is apparent that the domain-generality that is sometimes seen in task performance in younger adults becomes more common with increasing age (Hartley et al., 2001). This is particularly true within the visual domain and may be a reaction to the increased age-related decline in visuospatial abilities. Whilst dedifferentiation does occur in older adults, it is still possible to demonstrate the separable abilities that are seen in younger adults. This leads to difficulties in pinpointing not only the specific changes in task performance, but the conditions in which changes in task performance arise. Furthermore, it is unclear if changes in performance reflect active strategy choices, or passive reactions to a change in neuronal architecture.

This thesis will therefore explore the nature of visual task performance in older adults. Using a predominantly experimental approach the situations in which visual task performance is not only lower, but differentially affected by experimental variables will be explored. The general hypothesis will be that there is an age-related decline in visuo-spatial task abilities (Logie & Maylor, 2009; Johnson et al., 2010; Brockmole & Logie, 2013). However, this decline will also be characterised by differential patterns of performance compared to younger adults when presented with interference tasks. Scaffolding Theory (Park & Reuter-Lorenz, 2009) suggests that there will be compensatory recruitment in the face of declining task ability in older adults. Whilst this will not improve performance beyond that of the original systems it may help to maintain task performance in later life. Johnson et al., (2010) also showed that older adults relied on a more general task ability to complete visual tasks with increasing age. If compensatory recruitment is employed by older adults, then selective interference is likely to highlight the behavioural mechanisms at work. Ultimately this thesis will aim to identify the conditions in which older adults are likely to perform visual short term memory tasks in a different manner to younger adults, to see if there...
is a reliance on long term memory or previous experience in order to supplement visual task performance, and finally to assess if the relationship between specific task abilities is dependent on individual differences in older adults.
Chapter 2

This thesis tests the general hypothesis that there will be differential patterns of performance between young and older adults in A) visual working memory tasks when performed in conjunction with interference tasks, and B) visual memory tasks that can be aided by long-term memory activation. The first 3 experiments focused on assessing verbal interference tasks in young and older adults on both visual and verbal memory performance. This follows on from the general hypothesis presented in the literature review that older adults increasingly rely on general abilities and possible recoding strategies over and above specific visual imagery when performing essentially visual tasks. The first experiment is a replication of Brandimonte, Hitch, and Bishop’s (1992) paper concerning verbal overshadowing in visual imagery. Experiment 2 will assess the changes in the classic double dissociation between visual/verbal memory and visual/verbal interference tasks (Cocchini et al., 2002; Logie et al., 1990) between young and older adults. The third experiment will focus on possible verbal interference in visuospatial memory stores that are concerned with simultaneous and sequential presentation of information in both young and older adults.

Experiment 1

Introduction and brief recap

As discussed in the opening chapter, the nature of presentation, or the content of to-be-remembered information in any given short-term memory task can affect the manner of encoding. Baddeley (1983; 1986) made the broad distinction between visual and verbal tasks, such as memory for words, or memory for pictures, but there is an element of cross-modal encoding within tasks that can often lead to improved performance and can be identified through selective interference tasks. The visual similarity effect, as displayed by Saito et al., (2008), visual bootstrapping, (Darling et al., 2010; 2012), or improvement in Ravens Progressive matrices after verbalising instructions in older adults (Fox and Charness, 2010) have all demonstrated that cross-modal encoding can be of benefit to memory task performance. The nature of this
interaction between separate abilities changes across the lifespan. Interference tasks and changes in residual variance have shown specifically that visual abilities rely on more general abilities (rather than on an increase in task specific ability) with age (Chen et al., 2002; Johnson et al., 2010).

What then drives these examples of crossover encoding? Is there an automatic form of dual-coding, and if so is it always beneficial to memory performance? Can it lead to a reduction of some of the richness of information at encoding? Cowan (2005, p86-88) suggests that the process of chunking may be of benefit within the EPM in order to increase the information that can be held in the focus of attention. But does ‘chunked’ information contain the same richness of detail as ‘non-chunked’ information? Can chunked information be manipulated in the same manner as an individual item? The data from the literature are not clear, Brandimonte, Hitch, & Bishop (1992) demonstrated that cross modal performance, such as verbal recoding of visually presented information in a mental image rotation task does not always lead to a benefit in task performance. However, Alnajashi, Brown, Allen, & Mon-Williams (2007) attempted to replicate the verbal overshadowing effect displayed by Brandimonte et al. and did not repeat the findings. Darling et al. (2012) found that visual bootstrapping was only of benefit when to-be-remembered information was presented in a familiar format. So as well as questions relating to the replicability of cross-modal encoding effects in younger adults there is the question of whether the nature and frequency of this cross-modal encoding is the same across the lifespan? The Scaffolding Theory of Aging and Cognition (STAC) suggests that compensatory recruitment in the pre-frontal cortex as a reaction to increased task difficulty occurs more frequently with increased age. Behaviourally this could manifest itself in greater use of generalised task processes (Chen et al., 2002). It is possible then that processes such as verbal recoding, or chunking of information may be a more common occurrence in older participant’s as individuals seek to maintain memory performance.

This experiment attempted to replicate the results of Brandimonte et al. (1992) with younger and older adults in order to assess the presence of cross-modal encoding, and the effects of interference tasks at different stages of the lifespan.
The original study

The general hypothesis of the original study was that the verbal encoding or maintenance of visual stimuli in short term memory affects the long term memory representation of information and in turn impairs subsequent mental imagery tasks due to a loss of specific visuospatial information. This was based on a general understanding that verbal processing could in certain cases facilitate subsequent recall of information (Craik & Tulving, 1975), and on the knowledge that the verbal recoding of visual images was not a global phenomenon, but depended on the nature of the visual image being presented. This was shown by Schooler & Engstler-Schooler (1990) who demonstrated impairment in recognition for faces when participants had been asked to verbally describe their appearance at presentation. Brandimonte et al. suggested that the ability generate a visual mental image of an item is affected by the manner in which it was encoded. The argument being that participants would have a strong tendency to use a verbal code wherever possible when performing short-term memory (STM) tasks, even for visual material, and that this would affect the manner of the representation if the item became encoded in long-term memory (LTM).

In order to assess the possibility that the nature of stimuli presented affected the method of encoding Brandimonte et al. devised a two-way between subjects design where participants were asked to perform a mental image rotation task after being presented with one of two pattern sets consisting of apparently abstract shapes whilst either performing articulatory suppression (AS), or sitting in silence. The two sets of shapes were divided in to easy, and difficult to name patterns. This divide was based on a prior pilot experiment where participants had been asked to provide labels for the shapes, those that consistently received the same labels (such as ‘Umbrella’, See Brandimonte et al., (1992), for a full description) were placed in the easy-to-name set. All of the apparently abstract shapes, once rotated 90 degrees anti-clockwise would reveal two capital letters from the Roman alphabet. After a learning period where participants were repeatedly shown the six patterns from one of the two series, either under suppression or in silence, a recall phase began where participants were asked to imagine rotating the shapes and to identify the two capital letters. Brandimonte et al. found that AS improved the identification of letters in the easy-to-name condition, but
had no effect in the difficult-to-name condition. It was suggested that the use of AS prevented verbal encoding of the easy-to-name shapes, thus promoting encoding based on the visual characteristics of the shape and allowing for a mental image to be rotated. Having attempted to reduce the availability of verbal encoding in one experiment, the authors attempted to encourage verbal encoding in a second experiment by presenting shapes alongside a verbal label. It was found that performance on the difficult-to-name shapes was hampered by the inclusion of a label. It is possible that this is an example of what was described as verbal overshadowing, where erroneous verbal information was impairing the subsequent need to recall the visual characteristics of the item.

Brandimonte et al. concluded that 1) wherever possible participants will attempt to use verbal encoding of information. 2) Verbal encoding will impair performance on a subsequent imagery task that requires information about the visual characteristics of an item.

This simple theoretical interpretation maintains that what subjects learn about the visual characteristics of a stimulus is influenced by the availability of verbal codes. (Brandimonte et al. 1992. p453)

The data from the Brandimonte et al. study supports the idea that the creation of a phonological code for an item, even if it is visual in nature can lead to an impairment in the ability to recall or manipulate specific visual characteristics. Logie (1995) suggested that this verbal encoding leads to the retention of a prototypical, rather than specific version of the to-be-remembered information and as such, features that are visually salient in any presented information may be lost in a generic representation of a similar item that lends itself to sub-vocal rehearsal. This form of explanation is also commensurate with the EPM (Cowan, 1998; 2005). Cowan suggested that information in short term memory is a subset of activated long-term memory. If the information presented in the experimental task was too great to be held in the focus of attention, then some form of chunking process may have led to a reliance on prototypical versions of information in LTM. This explanation of performance is also commensurate with later iterations of the MCM (Baddeley, 2000; Logie, 2011). It is hypothesised that the binding between information from the visual and verbal systems
is moderated by the episodic buffer (Baddeley, 2000), a system of binding information which shares similarities with Cowan’s focus of attention (Cowan, 2005).

There are however certain issues with the interpretations put forward by Brandimonte et al. The positive effect of AS on the mental image rotation task was not replicated by Alnajashi et al. (2007) who found a generally negative effect of AS in both the easy and difficult-to-name conditions. Logie (1995, p40) questioned the argument that articulatory suppression alone is enough to prevent verbal encoding of an object, suggesting instead that the use of articulatory suppression in this task is preventing the maintenance of the to-be-remembered information. The information may be encoded visually, but in order to be maintained between retention and recall a form of verbal coding is used where possible, and this in turn could lead to the loss of some visually specific information. However, Logie did not question the idea that mental imagery tasks are open to various forms of strategy use and that this may be apparent in the results of Brandimonte et al. Having seen in the opening chapter that both visual memory and memory performance in ageing are open to strategy use then it was pertinent to replicate this study in young adults, along with the addition of an older experimental group.

A working hypothesis for this study was that younger adults would replicate the findings of the Brandimonte et al. (1992) study, bearing in mind that the results of Alnajashi et al. contradicted these findings. It was also expected that the older adults would show the positive effect of articulatory suppression, as demonstrated by Brandimonte et al. This is due to the increase in reliance on general abilities and compensatory recruitment when performing visual tasks that is seen in old age (Johnson et al., 2010; Park & Reuter-Lorenz, 2009), specifically the increased relationship between verbal naming ability and memory for spatial location in older adults that was demonstrated by Hartley et al. (2001).
Methods

Design

The study took the form of a between-subjects design, with 4 conditions, presentation of the easy, or hard to name pattern set, with, or without articulatory suppression.

Participants

120 participants from two age-groups (60 aged 18-25, 60 aged 60-75) were recruited. The younger participants were recruited through the University of Edinburgh recruitment website that offers temporary employment for students, or were completing the study for course credit. The older adults were recruited from the University of Edinburgh Psychology department volunteer panel, a database of community-dwelling adults from across Scotland who are prepared to give their time to psychological research, and from recruitment leaflets left at various community halls, civic centres and bowls clubs.

Materials

The stimuli from Brandimonte et al. (1992) were used. Two stimuli sets, one deemed as easy-to-name the other deemed difficult-to-name each containing 6 patterns were used. (See fig. 2.1) The ease by which the patterns could be named had been determined prior to the Brandimonte et al. experimental study. Patterns had been placed in the easy to name category if there was 50% agreement on the possible names for the shape between 15 pilot participants (See Brandimonte et al. 1992, for full details)

All patterns consisted of straight or curved lines, and when rotated 90 degrees anti-clockwise, represented two capital letters from the Roman alphabet. Patterns were presented on pieces of white card measuring 20cm x 20cm and were identical to those used in the Brandimonte et al. study.
Figure 2.1: Experimental stimuli from Brandimonte, Hitch, & Bishop (1992)

Procedure

As with previous versions of this study, participants took part individually in a 10 minute testing session. Participants were presented with each stimulus set 3 times, with each pattern being shown for 5 seconds at a time. A small pause to allow the participant to ask questions, or take refreshment was included between each run-through.

For those in the articulatory suppression conditions, the required rate of suppression (1 utterance per second) was demonstrated using a metronome prior to presentation of the to-be-remembered information. Once participants were demonstrating suppression at the required rate, the metronome was switched off, participants continued to repeat the sound ‘la, la, la, la’ and presentation of patterns began in the same manner as for those in the non-suppression conditions.
Following presentation of all to-be-remembered items participants were shown a training figure and asked to rotate it 90 degrees anti-clockwise to reveal the hidden capital letters. All participants were able to complete this training task. Having completed training the experimenter asked participants to recall each shape presented to them, rotate them through 90 degrees anti-clockwise and attempt to identify the two letters within.

**Results**

Sixty young adults (40 females, 20 males, mean age = 19.92, $SD = 2.35$; mean education level = 2.33, $SD = .66$) (Education levels: 1 = did not finish high school, 2 = finished high school, 3 = undertaking, or completed undergraduate degree, 4 = enrolled in or completed postgraduate degree) and 60 older adults (35 females, 25 males, mean age = 67.42, $SD = 4.00$, mean education = 2.84, $SD = .71$). Older adults had a significantly higher level of education, $t(58) = -3.88$, $p < .001$. However, all the majority of younger adults were in higher education and were on course to reach the same level of education as the older group.

As with the original study and with subsequent attempts at replication participants’ scores were based on their ability to identify letters with the patterns. Therefore participants could score 0, 1 or 2 for each item, with a maximum score of 12.

**Comparison of both age groups**

A 2 (age group) x 2 (Pattern Set) x 2 (Suppression condition) between subjects ANOVA was conducted to assess for differences in memory performance between young and older adults. There was a main effect of age, $F(1,112) = 4.15$, $p < .044$, $\eta^2_p = .036$. Younger adults had higher mean scores (7.18, $SD = 2.49$) than older adults (6.27, $SD = 2.81$). There was a main effect of pattern set, $F(1,112) = 4.15$, $p < .044$, $\eta^2_p = .036$. There were higher scores in the easy-to-name set (7.18, $SD = 2.65$) than in the hard-to-name set (6.27, $SD = 2.52$). There was a main effect of suppression, $F(1,112) = 5.45$, $p < .021$, $\eta^2_p = .046$. There were higher scores in the no suppression condition (7.25, $SD = 2.58$) than in the suppression condition (6.20, $SD = 2.58$). There was no age group x pattern set interaction, $F(1,112) = .858$, $p < .356$, $\eta^2_p = .008$, no
age group x suppression interaction, $F(1,112) = .309$, $p = .579$, $\eta^2_p = .003$, or age group x pattern set x suppression interaction, $F(1,112) = 1.00$, $p = .319$, $\eta^2_p = .009$. There was a pattern set x suppression interaction, $F(1,112) = 6.54$, $p < .012$, $\eta^2_p = .055$. Bonferroni adjusted t-tests showed there was no effect of suppression in the easy-to-name condition, $t(58) = .145$, $p = .885$ (Suppression mean = 7.23, $SD = 2.43$, No Suppression mean = 7.13, $SD = 2.90$). There was a negative effect of suppression in the difficult-to-name condition, $t(58) = -3.73$, $p < .002$. (Suppression mean = 5.17, $SD = 2.25$, No Suppression mean = 7.37, $SD = 2.25$). There was no difference between scores on the two pattern sets in the No Suppression condition, $t(58) = -.348$, $p = .729$. However, in the Suppression condition, scores were significantly higher on the Easy-to-name pattern set compared to the difficult to name pattern set, $t(58) = 3.37$, $p < .002$.

**Replication with young adults**

Due to the overall effect of age, and in order to compare young and older adult performance with the original Brandimonte et al. (1992) paper, separate ANOVAs for each age group were conducted.

**Overall score analysis**

The mean score in the easy-to-name condition with no suppression was 7.73 ($SD = 2.34$) in the suppression condition it was 7.13 ($SD = 2.64$). In the difficult to name condition with no suppression the mean score was 7.93 ($SD = 2.31$) and in the suppression condition it was 5.93 ($SD = 2.19$). As with the Brandimonte et al. study a two-way between groups ANOVA with factors of pattern set (easy/difficult to name) and suppression (with/without) was conducted. There was a significant negative effect of suppression, $F(1,56) = 4.485$, $p < .039$, $\eta^2_p .074$. Unlike the original study there was a negative effect of suppression on item recall for younger adults.

There was no effect of pattern set, $F(1,56) = .663$, $p = .419$, $\eta^2_p .012$ and no interaction between suppression condition and pattern set, $F(1,56) = 1.30$, $p = .259$, $\eta^2_p = .023$. Crucially this lack of interaction differs from the original study’s findings that suppression affected the easy-to-name pattern set in a different way than it affected the
difficult-to-name pattern set. The comparison of participants’ scores between studies can be seen in figure 2.2.

Assessment of Older adults

Overall score analysis

The mean score in the easy-to-name condition without suppression was 6.53 ($SD = 3.34$), and 7.33 ($SD = 2.29$) with suppression. In the difficult-to-name condition the mean score without suppression was 6.80 ($SD = 2.11$), and with suppression was 4.4 ($SD = 2.26$). Again a two way factorial ANOVA was conducted. In contrast to the Brandimonte study there was no main effect of suppression, $F(1,56) = 1.48, p = .229, \eta^2_p = .026$, there was also a main effect of pattern set, $F(1,56) = 4.11, p < .047, \eta^2_p = .068$, with higher scores in the easy-to-name pattern set. The interaction of suppression and pattern set shown in the Brandimonte study was seen, $F(1,56) = 5.92, p < .018, \eta^2_p = .096$. However, unlike the original study, Bonferroni adjusted t-tests showed that there was no effect of suppression in the easy to name condition, $t(28) = .766, p = .450$, and a negative effect of suppression in the difficult-to-name condition, $t(28) = -3.01, p < .012$. There was no difference between scores on the two pattern sets in the No Suppression condition, $t(28) = -.262, p = .796$. However, in the Suppression condition, scores were higher in the Easy-to-name pattern set compared to the Difficult-to-name condition, $t(28) = 3.53, p < .002$ (See fig. 2.2).
Figure 2.2: Mean performance for easy and difficult to name patterns with and without AS. Data on the left are from Brandimonte et al. (1992), data on the right are from this study. (Error bars represent Standard Error of the Mean; these were unavailable for the Brandimonte et al. data.)

Discussion

The initial analyses within this experiment assessed young and older adult performance in a replication of the Brandimonte et al. (1992) mental image rotation task. A 3 way ANOVA showed main effects of age group, pattern set, and suppression on the number of items recalled. Performance was generally lower in older adults, in the difficult-to-name pattern set, and under the articulatory suppression condition. There was a pattern set x suppression interaction. Suppression had a negative effect on performance in the difficult-to-name condition, but had no significant effect in the easy-to-name condition. This did not replicate the positive effect of suppression in the easy-to-name condition seen in the original Brandimonte et al. (1992) study.

Due to the age group effect, and in order to compare each age-group with the original study, separate ANOVAs were carried out with each age group. The younger adults demonstrated a significant negative effect of suppression with no suppression x pattern set interaction. Again, this was a failure to replicate the positive effect of suppression in the original study. The older adults showed no main effects of pattern set or
suppression. However, there was a pattern set x suppression interaction. This showed that older adults showed the negative effect of suppression in the difficult-to-name condition but did not show any significant effect of suppression in the easy-to-name condition.

The data for both young and older adults do not replicate the findings of Brandimonte et al. (1992). Articulatory suppression has a generally negative effect on mental image rotation performance for young adults, and a negative effect on performance for older adults when the items for recall are difficult to name. One question that arises from this is, why are older adults not affected equally by suppression when pattern sets are easy-to-name or difficult-to-name?

As suggested by Logie (1995, p34), the application of strategy use in a memory task may be highly related to individual differences (See Logie et al. 1996 for experimental data). The between-groups nature of the task led to an n of 15 in each condition, within these groups there was no control, or self-reports of the methods of task performance employed by participants. The method by which individuals transfer information from short to long-term memory may be highly variable and any individual effects may have been lost within the group means. However, the data seen do match the general findings of Alnajashi et al. (2007) and may reflect a use of verbal coding in mental image rotation tasks in young and older adults.

The negative effect of suppression on performance in the difficult-to-name task, and the lack of effect in the easy-to-name task suggest that verbal coding can also be of benefit to, or at least not detrimental to older adults. What is key is understanding why suppression hindered performance in the difficult-to-name task but not the easy-to-name task. The data from the difficult-to-name task would suggest that older adults rely on a form of verbal coding in order to perform mental image rotation tasks. However, it does not explain why this reliance is on items that are supposedly less likely to be named. The data could represent a declining ability in visual imagery in older adults. In the difficult to name task older adults may rely on verbal recoding of the information presented as there may not be a readily available prototypical representation in LTM. In the easy to name task, for older adults the inherent
nameability of the shapes may lead to a quick a robust representation being held in LTM. Failure to suppress sub-vocal rehearsal may actually damage the integrity of the image through excessive verbalisation. It may be that older adults are prone to using verbal strategy for encoding and maintenance when the items lend themselves to such a strategy even if it is not beneficial for the recall setting, hence the effect of AS on the easy-to-name items. In a situation where a visual strategy for encoding is more appropriate, such as the difficult to name setting then the hindrance may come from interference in retention. Explanations such as these would imply that older adults are unable to inhibit sub-vocal processes when presented with to-be-remembered information. This would be commensurate with Hasher & Zacks (1988) and suggestions by Chen et al. (2002). This interpretation is of course, purely speculative, and further research will need to focus on tasks with shorter encoding-maintenance-retrieval procedures in order to attempt to isolate specific mechanisms at work.

The data seen here cannot initially be taken as a rejection of the dull hypothesis. The three-way ANOVA revealed no age group interactions with the experimental factors. The overall suppression effect in the young adults, and the pattern set x suppression interaction in the older group suggest that there are some differences in the either the effects of stimuli on older adult task performance, or the manner in which older adults perform tasks. The nature of the task undertaken in this experiment does not allow for a clear understanding of where these differences lie. Future research will need to assess both young and older adults on non-verbal interference tasks as well as suppression tasks. This will allow for an understanding of the nature of dual-task performance across the lifespan. As yet, it is unclear if young and older adults show differential interference only in visual memory tasks with verbal interference. The data here may simply demonstrate overall changes in dual-task ability, rather than specific difference in visual memory performance.
Experiment 2

Introduction

The purposes of this study were to explore further the possibility that young and older adults do not necessarily perform visuo-spatial tasks using the same cognitive functions. Specifically, it is possible that older adults aid performance on visual tasks through processes such as verbal recoding. Experiment 1 demonstrated that there are some differences in the effects of articulatory suppression on a mental image rotation task between young and older adults, depending on the nature of the stimuli presented. This experiment will focus on working memory tasks and on replication of the classic double-dissociation of visual and verbal interference tasks on visual and verbal memory tasks (Logie et al., 1990).

The dissociation between verbal and visual working memory storage is one of the most robust findings from the working memory literature based on the MCM (Baddeley, 1983; 1986; 2000; Logie, 2011). Logie et al. (1990), Farmer, Berman and Fletcher (1986) Cocchini et al. (2002) and Gruber & Von Cramon (2003) have all demonstrated greater interference on working memory tasks when two tasks from the same domain (i.e.: a verbal memory and a verbal interference task) are performed compared to when two tasks from separate domains are performed. Logie et al. (1990) demonstrated that participants could perform a verbal task at 80% of single-task ability when combined with a visual task, and at less than 40% when combined with another verbal task. A similar pattern was found with visual task ability.

As has been seen in the in the opening chapter, and in Experiment 1 of this thesis, whilst working memory tasks are intended to be process specific, there is an element of process impurity that arises when task stimuli lends itself to multidimensional encoding (Brown et al., 2006; Darling et al., 2012). Logie (2011) characterises working memory as an overarching system comprised of many components, of which some are specialised for certain types of information. There is evidence to suggest,
through both experimental and correlational research that with increasing age, there is an increasing reliance on more generalised processes to carry out tasks that are intended to measure visual working memory. Johnson et al. (2010) identified an increase in reliance on general ability, rather than task specific ability in order to complete visual tasks (the VPT and a colour/shape feature binding task) in older adults. Conversely performance in verbal tasks (digit span and WM span) relied on more task specific variance with age. Hartley et al. (2001) and Chen et al. (2002) have also identified an age related dedifferentiation in visuospatial abilities. This possible dedifferentiation is accompanied by a relatively greater decline in visual, compared to verbal abilities in older adults. Logie and Maylor (2009) described the course of 5 short term memory tasks using data from the BBC memory studies. Performance on the verbal tasks was generally protected from decline until the 65-70 year-old age group, whereas decline in visual task ability began at around the age of 40 and continued into the 85+ category. Park and Reuter-Lorenz (2009) described older adult cognitive task performance within the framework of the Scaffolding Theory of Ageing and Cognition (STAC) (See Chapter 1 for a full exploration). The general tenet of STAC is that older adults compensate for decline in task specific architecture such as ventral-visual pathways by increasing frontal recruitment in order to maintain task performance. It is posited that whilst this will never improve performance over and above that of the original architecture, it does represent an adaptive response to increasing challenges such as task difficulty, or declining cognitive ability. Finally, it is suggested that this compensatory recruitment is not purely an age-related response. Scaffolding is seen as a response that will be employed by both young and older adults when the requirements of the task exceed the capabilities of task specific architecture. However, the level at which this will occur is much lower in older adults than it is in younger adults.

This experiment explored the possibility that verbal recoding of visual information is a response to the decline of visual working memory in older adults. Brown et al. (2006) demonstrated that the availability of verbal encoding was of benefit to younger adults’ visual patterns task performance (see Chapter 1 for a review). However, as was explored in Experiment 1, Brandimonte et al. (1992) found a negative effect of
available verbal coding in a mental image rotation task. The replication within in this thesis did not find this effect with young adults or older adults.

The evidence from the literature suggests that a) visual abilities decline at a faster rate in older adults than verbal abilities do (Park et al., 2002; Logie & Maylor, 2009). b) Verbal recoding of visual information is a phenomenon that occurs in various forms, with varying degrees of success across a number of paradigms (Brandimonte et al., 1992; Brown et al., 2006). And c) verbal recoding, or at least verbalising has been shown to help older adults visual task performance (Fox & Charness, 2010). In order to assess whether this has an effect on the double-dissociation between visual and verbal tasks in young and older adults this experiment participants were tested on their visual and verbal working memory task ability. For both tasks memory performance was assessed under visual and verbal interference during maintenance of to-be-remembered information.

It is expected that, in accordance with Logie et al. (1990) and Cocchini et al. (2002) there will be a significant difference between performances in the recall tasks depending on the nature of the interference task. Interference tasks that are domain specific to the recall task should produce a significantly greater effect on performance than non-domain-specific tasks. However, if we take it account the findings of Logie and Maylor (2009), Johnson et al (2010), and Experiment 1 of this thesis then it is expected that older adults will suffer verbal interference effects on a visual task to a greater extent than younger adults. Due to the relative age insensitivity of verbal memory tasks (Johnson et al. 2010) the relative effects of a verbal interference task on a verbal recall task should remain unaltered throughout the lifespan.

**Methods**

**Design**

This was a mixed design with two age groups and two repeated measures factors (Memory task and Interference task)
Participants

36 participants (18 young aged 18-25, and 18 older aged 60-70) were recruited. Younger participants were recruited through the University of Edinburgh subject pool, where participants receive course credit for participation. Older participants were recruited using the University of Edinburgh Volunteer panel and were paid £6 in remuneration for their participation.

Verbal Recall task

Participants were required to carry-out a version of the Daneman & Carpenter (1980) WM span task. The sentences used in the study were based taken from the Baddeley et al. (1985) WM span task. Participants were presented with a series of sentences and are required to indicate verbally whether a sentence was truthful or not, as well as maintaining the last word from each sentence. After a 10 second interference period, the recall task required serial-order recall of the last word in each sentence. This sentence reading task was used over simple list learning as the act of reading out sentences would prevent attempts at sub vocal rehearsal until the interference phase started. Furthermore, Park et al. (2002), and Logie et al. (2015) highlighted that older adults are likely to show greater task decline in memory tasks that require processing over and above that of simple storage.

Before each set of sentences a fixation cross was displayed for 1000ms. Each sentence was displayed for 3000ms. There was a 500ms blank screen displayed between each sentence. After the presentation of the final sentence in each block there was a final 500ms gap. A yellow screen appeared and depending on the condition participants were prompted to begin either the tapping or suppression interference tasks. After 10 seconds this screen turned blue and participants were instructed to begin recall. The next presentation sequence did not begin until participants had indicated that they had finished recalling to the best of their ability. Participants were given a maximum of 20 seconds to recall the words. At the lowest level of task difficulty participants were required to remember words from 3 sentences, at the highest level they were required
to remember words from 7 sentences. There were 3 sets of presentations at each level. In total participants had 75 words to recall in each task.

Scoring for the task was based on the total amount of words recalled; this was chosen over a span measurement following the analyses of Unsworth and Engle (2007a), who found that continuous measures were most sensitive to an individual’s performance levels than a span measuring procedure. The stimuli were randomly allocated to each trial and then presented in this fixed random order to all participants.

**Spatial Memory Task**

The spatial task used in this experiment was the Shah and Miyake (1996) Letter ‘R’ task. The letter R was developed to provide a visuospatial counterpart to the verbal WM Span task. Participants were presented with either the letter R, L, G, F, or J at one of 7 angles on screen. Participants were required to indicate whether the letters presented were in a standard, or mirrored format, as well as maintaining the orientation of each letter. The memory task required serial order recall of the letter orientations. This combination of judgement and recall is analogous to the WM span task described above. The original Shah and Miyake study showed that this task was an accurate measure of visuo-spatial ability and did not correlate with verbal ability (Shah and Miyake, 1996).

Letters were presented for 3000 ms. This matched the presentation times of the WM span task. Participants were initially asked to recall the location of two letters, this rose up to 5 letters by the end of the task. Each level had 5 sets of presentations. After the last presentation at each level a yellow screen was presented. Depending on the condition, participants were prompted to undertake the tapping or suppression task. After 10 seconds this screen turned blue and participants were instructed to start indicating letter locations on the response sheets provided. The next presentation set did not begin until the participant indicated that recall had finished. As with the verbal task, participants were given a maximum of 20 seconds to recall the letter locations. In total participants had 70 letter locations to recall in each of the visual task
conditions. A continuous measure of total correct locations was used for the same reasons outlined in the explanation of the verbal working memory task.

Both tasks were computerised using E-prime 2.0. The tasks were presented to participants on a 16 inch screen on a computer running Windows Vista software. Sentences were presented in size 20 Times New Roman font. Letters in the spatial task measured 400mm in height. Word recall was carried out verbally and marked by the experimenter against a list of correct responses. Spatial location of letters was marked on pieces of paper and marked by the experimenter at a later date. Participant’s answers were marked on an 8 point compass, with the top orientation marked out. This then represented the 7 possible angles that the letters could be presented at (See Appendix A). These were marked after the participant had left. Judgement of non-truthful/truthful sentences or mirror/non-mirrored letters was not recorded.

**Articulatory Suppression**
Participants were instructed to repeat the digits 6 and 2 alternately. During practice tasks participants were trained to repeat two numbers per second. Once participants had reached a satisfactory level they were told to attempt to maintain this rate of repetition for all trials (Participants were trained to vocalise as close to twice a second as they could). Rate of repetition was taken as a measure of performance. Therefore it was decided that participants would repeat a pair of single digit numbers, so that clear, separate sounds could be made and that the experimenter could be sure of the rate of repetition. The numbers six and two were chosen at random and were used for all participants.

**Sequential tapping**
Participants were asked to tap out a pre-determined ‘figure of 8’ sequence on a 9 button keypad. The buttons were 30mm wide with a 3mm gap between them. As with the suppression task, participants were trained to tap as close as possible to a rate of two taps per second and then asked to maintain their rate of tapping throughout the study (See Appendix A). Performance was assessed on the rate of tapping and on percentage
accuracy compared to the predetermined pattern at all levels of difficulty of the memory tasks.

The tapping box used ‘timekeys’ version1.1 standalone software and the tapping box and was designed at the University of Edinburgh. Tapping accuracy was saved to a Microsoft Excel workbook.

**Procedure**

All participants were tested individually with the experimenter present at all times. An equal number of participants took either the visual or the verbal task first. Domain specific interference tasks were performed first in both visual and verbal tasks.

**Figure 2.3:** Shows the screen process of the spatial memory task. The WM span task follows the same process with sentences presented in place of letters. However, there is a 500ms gap between each sentence presentation to allow participants to complete reading the sentences out aloud.

Participants undertook a training phase in their initial memory task. This was used to show the ‘Encoding-Interference-Recall’ routine of the task, and the nature of their initial memory task. The practice period also involved learning the required tapping pattern as well as practicing repeating ‘six, two, six, two, six…’ at the correct rate of
repetition. After the experimenter was satisfied that they were able to tap the pattern correctly and maintain their tapping or suppression rates the tasks began. All participants sat through all task conditions from the lowest to the highest level of presentation. After completing their initial memory task with both interference tasks participants were given a 5 minute break and were offered a beverage. This was followed by a second training phase explaining the nature of the second memory task. This was then carried out from lowest to highest span presentation with both interference tasks.

**Results**

**Participants**

36 participants were tested, 18 young (18-25, mean age = 20.22, \( SD = 2.78 \); mean education = 2.61, \( SD = .85 \), 11 Females, 7 Males) and 18 older (60-70, mean age = 64.06, \( SD = 2.53 \), mean education = 3.00, \( SD = .69 \), 10 Females, 8 Males). Education level was measured on a 4 point scale (1 = Did not finish high school, 2 = Finished high school, 3 = Undergraduate degree, 4 = Postgraduate degree). There was no difference in education level between groups, \( F(1,34) = 2.28, p = .14 \).

**Effects of interference tasks on memory scores**

A 2x2x2 mixed ANOVA with age-group as a between subjects factor, and task type (visual/verbal), and interference task (suppression/tapping) as within subjects factors was conducted. There was a main effect of age group, \( F(1,34) = 17.83, p < .001, \eta^2_p = .34 \), with younger adults (mean score 52.69) having higher scores than older adults (mean score 40.86). There was no main effect of interference task, \( F(1,34) = 2.48, p = .125, \eta^2_p = .07 \) and there was a marginal effect of task type, \( F(1,34) = 3.942, p = .055, \eta^2_p = .10 \), scores were slightly, but not significantly higher in the verbal task than in the visual task (verbal mean= 48.63, \( SD = 8.09 \), visual mean = 44.91, \( SD = 14.57 \)), \( t(35) = 1.90, p = .07 \).
There was a task type x age group interaction, $F(1,34) = 4.37, p < .044$, $\eta^2_p = .11$. t-tests with Bonferroni adjustments showed younger adults had no difference between visual and verbal task scores. Older adults displayed higher scores in the verbal condition, $t(17) = 2.30, p < .034$. There was an interference type x age group interaction, $F(1.34) = 5.24, p < .028$, $\eta^2_p = .133$. Younger adults showed no difference in performance under suppression or spatial tapping across both memory tasks, $t(17) = .509, p = .617$, older adults showed lower scores when performing articulatory suppression, compared to performing spatial tapping, $t(17) = -2.71, p < .015$. There was a task type x interference interaction, $F(1,34) = 70.16, p < .001$, $\eta^2_p = .67$. The verbal task was most affected by articulatory suppression, $t(35) = -7.12, p < .001$ whilst the visual task was most affected by the spatial tapping task, $t(35) = 4.10, p < .001$. Finally there was a three-way task type x interference x age group interaction, $F(1,34)= 16.58, p < .001$, $\eta^2_p = .33$. In the verbal task, both young and older adults demonstrated a greater effect of suppression on performance (Young, $t(17) = -7.57, p < .001$, Older, $t(17) = -4.03, p < .001$). In the visual task, younger adults demonstrated a greater negative effect of spatial tapping, $t(17) = 7.30, p < .001$, whilst older adults were equally affected by both interference tasks, $t(17)=.467, p = .646$.

**Fig 2.4:** Mean scores on visual and verbal tasks in both interference conditions. (Error bars represent the Standard Error of the Mean.)

**Mean Visual and Verbal Task Scores by Interference Condition**
Changes in secondary task performance

The effect of increasing memory load on interference task performance was assessed. Two -way repeated measures ANOVAs were carried out on the mean scores from all interference tasks. Memory load (the number of items to be recalled in each memory condition) was the first factor, age group was the second factor. The dependent variable for articulatory suppression was the mean rate of repetition during the 10 second maintenance period of the memory tasks. The dependent variable for the spatial tapping task were the mean rate of tapping during the maintenance period.

In the verbal task with articulatory suppression there was a main effect of memory load on the rate of suppression (Mauchly’s test violated, Greenhouse-Geisser used), $F(2.34, 79.34) = 6.84, p < .001, \eta^2_p = .17$. Bonferroni adjusted pairwise comparisons revealed that rate of repetition at the lowest memory load (3 words to remember, mean rate of repetition= $16.27, SD = 3.29$) was significantly lower than the rate of repetition with 5, 6, and 7 words to remember (5 words mean =17.01, $SD =3.65$ mean diff = - .81, $p < .002$, 6 words mean = 17.1, $SD = 3.78$, mean diff = -.822, $p < .05$, 7 words mean 17.27, $SD = 3.93$, mean diff = -.99, $p < .02$). There was no effect of age group, $F (1,34)= 1.001, p = .324$. There was no age group x task level interaction, $F < 1$. Therefore there was a general trend across both age groups for suppression rate to increase after the initial level of the memory task.
Fig 2.6: Mean utterance/tapping rates in interference tasks when maintaining information from verbal memory task (Error bars represent Standard Error of the Mean).

(Data for participant 30 were lost because of a technical failure, and as such they were excluded from the following analyses) In the verbal task with spatial tapping there was no main effect of memory load on rate of tapping. (Mauchly’s violated, greenhougeist geisser used, $F(2.24, 73.39) = .93$, $p = .45$, $\eta^2_p = .03$, or task level x age group interaction, $F(2.24, 73.39) = .654$, $p = .54$, $\eta^2_p = .02$. There was a main effect of age group, $F(1,33)=11.48$, $p < .002$, $\eta^2_p = .258$, the older group tapped at a faster rate than the younger adults (Young mean = 17.76 $SD = 3.82$, Older mean = 22.1, $SD = 4.77$). This is likely a reflection of older adults’ tendency to produce a faster rate of tapping in practice tasks, rather than a reflection on the experimental manipulations.

In both the visual task with suppression and the visual task with spatial tapping there was no effect of memory load on interference task performance, nor were there any age group interactions (Visual/Suppression: memory load, $F(1.97,66.89) = .86$, $p = .464$, $\eta^2_p = .03$; Age Group x Task Level, $F(1.97,66.89) = .07$, $p = .93$, $\eta^2_p = .002$) (Visual/Tapping: Task Level, $F(1.03,33.84) = 1.99$, $p = .168$, $\eta^2_p = .06$; Task Level x
Age Group, $F(1.03,33.84) = 2.07, p = .159, \eta^2_p = .06$) There was no main effect of age in either condition (Visual/Suppression, $F(1,34) = 2.67, p = .11, \eta^2_p = .07$; Visual/Tapping, $F(1,33) = .42, p = .52, \eta^2_p = .01$)

Fig 2.6: Mean utterance/tapping rates in interference tasks when maintaining information from visuo-spatial memory task (Error bars represent Standard Error of the Mean).

Discussion

The aim of this study was to replicate the domain specific interference seen in younger adults across the working memory literature (Cocchini et al., 2002; Logie et al., 1990; Logie et al., 2004) and to ascertain if the patterns of interference differ between young and older adults. The hypothesis being that there would be differences in the level of verbal interference experienced in the visual memory task, but that interference patterns would be matched in the verbal memory task. In accordance with our hypotheses there was a 3-way interaction between age group, task type, and interference task. This was characterised by domain specific interference, as shown by relatively lower task performance, in the verbal memory task with suppression for both age groups. In the visual task this domain specific interference was only seen in the younger group. The older group showed no difference in the level of interference from
either articulatory suppression or spatial tapping in the visual task. Therefore these data continues the line of already robust findings that support the MCM and suggests that domain specific interference is a greater hindrance to recall than non-domain specific interference in young adults. There is support for the greater reliance on non-task specific or general abilities in visual task performance with age (Chen et al., 2002; Johnson et al., 2010). The lack of age group differences in interference in the verbal task supports the results of Logie et al. (2004; 2007) in finding that older adults show no increased dual-task deficit compared to younger adults when conducting a memory task with a non-domain specific interference task.

The presence of the age group x task type interaction suggested a greater difference in the level of ability between visual and verbal task performance in the older adults. The younger adults showed no difference in the level of performance between visual and verbal tasks when interference tasks had not been taken into account. The older group showed significantly lower overall scores in the visual task compared to the verbal task. However, it is likely that this reflects the presence of two interference tasks that older adults found detrimental to visual task performance. Whether this is a product of declining visual task performance, or is in itself the cause of declining visual working memory task performance is not possible to explain with the data seen here, and is a question that will be returned to within this thesis. However, the data does suggest that older adults are not performing the visual task purely through verbal rehearsal. If this were the case then there would have been a greater effect of articulatory suppression than there was of spatial tapping, yet this was not the case.

The presence of the task type x interference interaction, which was characterised by greater domain specific interference in memory tasks across both age groups is further evidence for domain specificity, as suggested by Baddeley, (1983; 1986) and demonstrated by Logie et al. (1990) as a general and robust phenomenon within working memory architecture. It is possible that the age-related differences seen in the visual task with older adults represent a specific case of the hypothetical situations where domain general recruitment can maintain, or aid performance in older adults’ task performance (Park & Reuter-Lorenz, 2009).
There was no effect of increasing visual memory task difficulty on the rate of tapping or rate of repetition in either age group. In the verbal task with spatial tapping the increase in memory load had no effect on the rate of tapping. In the verbal task with articulatory suppression rates of repetition were increased when there 5, 6 and 7 words to remember compared to the rate of repetition at the lowest level, when there were 3 words to remember. It is possible that this represents participant’s becoming more familiar with the demands of the task; however it is likely that the requirement to articulate sentences during the presentation of to-be-remembered information leads to a brief dip in articulatory suppression during early presentations whilst older participants became more familiar with the requirements of the task.

A methodological issue with the spatial task does arise at the higher levels where participants are requested to remember up to 5 letter positions. There are only 7 possible answers and therefore the chances of a participant guessing correctly once two or three correct answers have been included are greatly increased. It is also possible that asking participants to recall the spatial location of items that are usually encoded verbally (In this case, capital letters) is likely to promote automatic verbal encoding. Future studies within this thesis will focus on tasks that allow for a greater range of responses, as well as making more specific manipulations of the level of verbal encoding available to participants. Future research within this thesis will also assess participants up to a maximum span measure, rather than the method seen in this study, where all participants are presented with all possible stimuli and a score is taken. In order to understand how older adults are performing memory tasks it is important to understand what happens at a level where a task can be consistently performed. The method of scoring here would allow both age groups to maintain a low span score whilst still increasing overall task score by recalling the first few items in any given presentation.

The data presented here corresponds with Perfect and Maylor’s (2000) rejection of the dull hypothesis, in that there is a differential decline in performance in older adults. The decline seen here is not a case of task performance becoming poorer across all
measures. The lack of selective interference effects in the spatial task in older adults is support for the hypothesis that older adults are likely to verbally recode visuo-spatial information and as such two further directions for research in this thesis are

1) To identify the mechanisms within visuo-spatial working memory that are being employed, or are declining. The data here cannot pinpoint changes in task performance to the inner scribe, or the visual cache. The visual task can be performed in a number of ways, either as list of instructions, as a sequential pathway, or possibly as locations on a clock face, or a compass. It is important to identify performance within the separable components of visuo-spatial working memory as outlined by Logie (1995).

2) There is a need to understand where the compensatory encoding is taking place. Is information being directly verbally recoded in the phonological loop? Or is it that the use of a strategy that pins the presented information to long-term knowledge of items such as clocks or compasses, lead to verbalisation? The effect of AS suggests that some form of sub-vocal rehearsal must be employed by older adults. Equally, the matched effect of spatial tapping on the visual task suggests that older adults are not using a purely verbal method to complete the tasks.

Whilst there is an age-related difference in visual task performance, it is not clear where within the cognitive architecture that this difference lays. For instance, does the sub-vocal rehearsal occur due to a poorer short-term memory store, or because of an inability to inhibit verbal recoding? Is it verbal encoding of information that is being disrupted, or verbal rehearsal that is being prevented? What is clear is that the mechanism of verbal working memory performance is relatively insensitive to age, and that older adults show differential patterns of interference in visual tasks. Further research will explore the nature of these differences.
Experiment 3
Introduction

The two previous studies within this thesis have indicated that there are differential patterns of interference in visual working memory tasks in older adults compared to younger adults. It appears that for older adults, performance in a visual memory task is more susceptible to the availability of verbal encoding, or the introduction of a verbal interference task. This study aimed to look at the effects of verbal interference on two separate visual memory tasks that tap separate resources within the visuospatial system. Participants undertook versions of the visual patterns task (VPT) with simultaneous and sequential presentation. The simultaneous VPT is intended to measure storage in the static visual component of STM, whilst the sequential task is intended to measure the performance of the spatial component (Della Sala et al., 1999). Both tasks were performed with and without articulatory suppression, this was intended to prevent sub-vocal rehearsal of presented information and allow inference as to the nature of any cross-modal encoding in older adults visual memory task performance.

As described previously within this thesis, the visual system of the MCM is posited to consist of two components, the visual cache, and the inner scribe (Logie, 1995). The visual cache is a store for static representations of information, such as pictures and objects. The inner-scribe is used for the rehearsal of spatial locations, and as such is needed for recall of patterns, sequences and movements (Logie, 1995, Logie & Pearson, 1997). The dissociation between storage for simultaneously and sequentially presented information has been demonstrated in numerous experimental studies (Della Sala et al. 1999; Logie & Pearson 1997; Pickering, Gathercole, Hall & Lloyd, 2001). Logie & Pearson (1997) gave children from 3 age groups (5-6, 8-9, and 11-12) recognition memory tasks for static visual patterns and for a sequence of movements. Across all groups, performance in the static task was higher than that in the sequential task. However, this difference increased in size from the youngest to middle group, and from the middle group to the older group. This was taken as evidence for separable components with a greater improvement in visual cache performance with age. Pickering et al. (2001) demonstrated a similar distinction using 5, 8, and 10 year old
children, using static and dynamic displays to distinguish between visual cache and inner scribe performance. Della Sala et al. (1999) also demonstrated this double-dissociation between simultaneous and sequential memory through the use of selective interference tasks.

As well as the considerable body of evidence demonstrating separable components within visuospatial working memory, there is also evidence to suggest that visual and spatial tasks differentially recruit executive strategies for task completion. Rudkin et al. (2007) found that oral random digit generation as an interpolated task had a greater negative effect on performance in a task requiring the processing of sequentially presented information than in a task requiring processing of simultaneously presented information. It is possible that the requirement to maintain a sequence in the correct serial order necessitates a greater recruitment of the attentional resources of the central executive. This has implications for any theoretical framework attempting to understand visual task completion in older adults. Chen et al. (2002), Johnson et al. (2010), and Park and Reuter-Lorenz (2009) all suggest that there is an increasing reliance on non-domain specific, general abilities in older adults’ visual task performance. What is currently not clear, are the exact components or methods of encoding that are recruited in this domain general task performance.

Data from the previous experiments within this thesis have suggested that verbal recoding of information through the use of the phonological loop is a candidate. This possibility was considered by Bopp and Verhaeghen (2007). It was suggested that an increase in the time taken to complete visual tasks in older adults may represent the time taken to verbally recode visual information. However Bopp and Verhaeghen went on to state that the increase in the time taken to complete tasks in older adults was not long enough to allow for a system of verbal recoding. The interpretation of Bopp and Verhaeghen appeared to be based on an assumption that older adults may initially attempt to perform visual tasks using visual mechanisms and then only turn to verbal components to improve, or maintain performance. However, it is possible that older adults automatically recruit verbal resources in order to perform visual tasks (Hartley et al. 2001). If the visual task being ascribed to older adults in any given experiment is akin to the sequential task used by Rudkin et al. (2007) then it is possible that the initial
allocation of executive attentional resources would require executive functions rather than an initial attempt to encode information using only visuospatial abilities. It may be that a number of visuospatial tasks also lend themselves to other forms of encoding or maintenance. The Shah and Miyake letter ‘R’ task used in Experiment 2 is presented as a visuospatial WM task, however it would be possible that a participant could recall the location of items using a numbering system, or by building a static image based on the location of each letter. The similarity in effects of articulatory suppression, and spatial tapping on the letter ‘R’ task for older adults in Experiment 2 may have been a product of the individual differences in older adult task performance. Whereby individuals would approach the task in a manner that suits them, regardless of the designated cognitive component the task is intended to measure. It is possible that spatial tasks such as the Shah and Miyake task, or any visual task using sequentially presented information are more open to the use of executive functions, or verbal recoding than tasks involving static images or patterns.

As such it was pertinent to investigate the effects of articulatory suppression on performance in both spatial and sequential versions of a visual task. In Experiment 3, participants undertook the VPT with simultaneous and sequential presentation of information. As with Experiments 1 and 2, articulatory suppression was used to restrict the use of the phonological loop, participants also carried out non-interference control conditions in both tasks. The data seen so far in this thesis led to the hypothesis that there will be a differential effect of suppression on visual task performance between young and older adults. As seen in this thesis and in Pickering et al. (2001) it is unlikely that there will be an effect of AS on performance in the visual memory tasks for younger adults. Rudkin et al. (2007) did show that an interference task involving oral production disrupted performance in a sequential task in younger adults, but it was the executive nature of the task, rather than the requirement to speak aloud that was deemed to be the source of interference. The introduction of a non-executive oral task in this experiment offered an additional test of that issue. A generally greater effect of suppression is expected in older adults. Johnson et al. (2010) have demonstrated that, within the visual domain there is a greater reliance on general, rather than task specific abilities in older adults, and experimental data in this thesis has shown differential effects of AS on older adults compared to younger adults. It was also hypothesised that
whilst older adults would show a general effect of suppression, there would be a greater interference from AS in the sequential memory task compared to the simultaneous task. Hartley et al. (2001) demonstrated a relationship between verbal task ability and spatial task ability in older adults that was not present in a younger group. Furthermore, Park et al. (2002) have demonstrated that older adults have greater difficulty in performing tasks that have a processing element. Taken in conjunction with the findings of Rudkin et al. (2007) it is likely that older adults will show interference effects from a verbal task in a spatio-sequential memory task. Finally, the Shah and Miyake task in Experiment 2 was a spatio-sequential task and demonstrated an effect of suppression that was equal to that of spatial tapping. This is remarkable considering that suppression has as large an effect on performance as a task that is specifically designed to interfere with performance on serial-order visual memory tasks such as the letter ‘R’ task.

**Methods**

**Design**

This was a mixed design study with two separate age groups and two repeated measures factors, memory task (simultaneous or sequential), and interference (articulatory suppression or no interference)

**Participants**

48 participants (24 young 18-25, 24 older 60-75) were recruited. Younger participants were recruited from the University of Edinburgh subject pool, or from SAGE, a part time recruitment website at the University of Edinburgh. Those from the subject pool received course credit; those recruited from SAGE received £5 for their time. Older adults were recruited from the University of Edinburgh Psychology department volunteer panel and were given £5 remuneration for taking part.

**Apparatus**

Participant and experimenter each sat in front of a box topped with a matrix of buttons. (See Appendix A) A wooden dividing screen prevented the participant from seeing the
experimenter. The experimenter could mark out a series of patterns using the box, and when ready, could be transferred as a simultaneous or sequentially displayed pattern in front of the participant. The length of display could be determined by the experimenter. Each button on the participant’s box measured 150mm x 150mm and the buttons were 15mm apart.

Matrices for recall were presented on 2x2, 3x3, 4x4, 5x4 and 5x5 grids. Respectively, each grid had 2, 4, 6, 8, 10 and 12 lights to recall. Different sized grids were created on the light box by overlaying black card ‘masks’ which obscured irrelevant squares from view. This process was used on the same apparatus by Niven (2010) as part of work forming a doctoral thesis.

Four separate pattern sets (From a 2x2 grid to a 5x5 grid) were created. A random number generator was used to choose which squares in the grid would be lit and unlit. These patterns were fixed for all participants, but pattern sets were presented in a counterbalanced order.

**Memory tasks**

The simultaneous task followed a similar method to that used by Logie and Pearson (1997), Della Sala et al. (1999) and Brown et al. (2006). Participants were presented with a pattern of lit and unlit squares and given the task to try and recall the position of the lit squares. As in Brown et al. study patterns were presented for 3000 ms, followed a by a 10000ms maintenance/interference interval, and finally time to recall the pattern presented. Each experimental condition would start with a 2x2 grid with the task of recalling the position of the 2 lit squares. This could increase all the way to a 5x5 grid with 12 squares to remember. Participants would sit through 3 patterns at each level of difficulty. Span level was deemed to have been reached when participants could no longer completely recall all the squares in 2 out of 3 presentations at any given level. Span was calculated as the mean amount of squares in the last 3 correctly recalled patterns (2 out of 3 patterns correct with 10 squares to remember and 3 correct with 8 squares to remember would equate to a span of 9.33). In the articulatory suppression condition participants were required to repeat the numbers 6 and 2 at the rate of 2 utterances per second (This followed on from the methods used in Experiment
2 of this thesis). In the non-interference condition participants were instructed to sit in silence. In both conditions the experimenter indicated when the 10000ms limit had been reached, and indicated that recall could now start.

The sequential task followed a broadly similar methodology to the simultaneous task. The key difference was that presentation of squares was now sequential, with each square within a pattern being displayed for 1000ms at a time, with a requirement for serial-order recall. As with the simultaneous task, participants would start with a 2x2 grid and continue until span level had been reached. Again participants undertook both an interference and non-interference version of the task.

**Procedure**

All trials took place in 7 George Square, the University of Edinburgh. Participants were tested one at a time and an experimenter was always present in the room. Older adults initially took the mini-mental state exam (MMSE) (Folstein, Folstein, & McHugh, 1975). Participants would initially sit through a trial task which featured 3 simultaneous and 3 sequential presentations of patterns on a 2x2 grid (These patterns were not used in the experimental condition). Adequate performance in the practice task was considered as 2 out of 3 patterns correct in both presentation conditions, however, all participants performed at ceiling level in the practice task. Participants were then given time to practice the required rate of utterance for the interference task. The experimenter would give feedback until participants felt comfortable with a rate of two utterances per second.

The experimental process would then start. All conditions were counterbalanced, so each participant was the only individual within their age group to sit through their particular order of conditions. All conditions would start with two squares to remember on a 2x2 grid and after 3 presentations would increase by 2 squares to remember and continue until span level had been reached. At the end of each condition participants would be offered a small break and a glass of water. Total experimental time ranged from 45 minutes to 60 minutes dependent on the ability of the participant.
Results

Participants

The 24 younger adults (15 females, 9 males) had a mean age of 22.25 (SD = 1.82) and a mean education level of 3.00 (SD = .72) (1 = did not finish high school, 2 = finished high school, 3 = undertaking, or completed undergraduate degree 4 = enrolled in or completed postgraduate degree). The 24 older adults (16 females, 8 males) had a mean age of 64.96 (SD = 2.35) and a mean education level of 2.79 (SD = .72) There was no effect of education on task score in either group (Young: F (1,21) = .09, p = .91, η²p = .01. Older: F (1,21) = .07, p = .93, η²p = .01). There was no effect of age on education level, F (1,46) = 1.00, p = .323. Older adults had a mean MMSE score of 29.08 (SD = .76). Participants in Experiment 3 had not taken part in Experiment 2.

Memory tasks

A 2x2x2 mixed ANOVA with age group as a between subjects factor, and task type (simultaneous/sequential) and interference (articulatory suppression/no interference) as repeated measures factors was conducted. There was a main effect of age group, F (1,46) = 29.39, p < .001, with younger adults demonstrating higher spans than the older adults. There was a main effect of task type, F (1,46) = 383.15, p < .001, η²p = .89 with lower scores in the sequential condition than in the simultaneous condition. (Young adults Simultaneous Mean = 8.75, SD = 1.31, Sequential Mean = 5.08, SD = .77, t (23), 14.75, p < .001. Older adults Simultaneous Mean = 6.94, SD = 1.08, Sequential Mean = 4.28, SD = .72, t (23) = 12.87, p < .001.) There was a main effect of interference, F (1,46) = 5.33, p < .025, η²p = .10, with lower performance under suppression compared to performance without suppression. There was also a task type x age group interaction, F (1,46) = 9.70, p < .003, η²p = .17, with a greater decline between simultaneous and sequential tasks in the younger adults compared to the older adults (Young mean decline = 3.67, SD = 1.22, Older mean decline = 2.66, SD =1.01, t (46) = 3.11, p < .01). There was no age group x interference interaction, F (1,46) = .70, p = .41, η²p = .015, no task type x interference interaction, F (1,46) = 1.04, p = .31, η²p =
Due to the main effect of age group in the between subjects ANOVA, separate repeated measures ANOVAs were conducted for each age group in order to further explore the main effects of interference and task type.

In the young group there was a main effect of task type, $F(1,23) = 217.77, p < .001$, $\eta^2_p = .90$, with lower scores in the sequential condition compared to the simultaneous condition. There was no effect of interference, $F(1,23) = .88, p = .36, \eta^2_p = .04$, and no task type x interference interaction, $F(1,23) = .005, p = .95, \eta^2_p = .001$.

In the older group there was a main effect of task type, $F(1,23) = 165.59, p < .001, \eta^2_p = .88$). There was also a main effect of interference, $F(1,23) = 6.50, p < .02, \eta^2_p = .22$) with lower scores under articulatory suppression than in the non-suppression condition. There was no task type x interference interaction, $F(1,23) = 3.09, p = .092, \eta^2_p = .12$.

**Fig 2.7:** Mean scores on simultaneous and sequential memory tasks with and without suppression (Error bars represent the Standard Error of the Mean)
Relative decline scores

The total number of ‘squares recalled’ in interference conditions were calculated as a percentage of scores in single-task conditions. A 2 x 2 mixed ANOVA with age as a between groups factor and relative decline (Simultaneous percentage decline/sequential percentage decline) as a repeated measures factor was conducted in order to compare the relative declines in performance between young and older adults. There was no main effect of age group, $F(1,46) = 55.47, p = .61, \eta^2_p = .01$. There was a main effect of relative decline, $F(1,23) = 4.50, p < .04, \eta^2_p = .09$ with greater decline in the sequential task compared to the simultaneous task. There was also a relative decline x age group interaction, $F(1,46) = 4.81, p < .03, \eta^2_p = .10$. Bonferroni adjusted t-tests revealed a significant difference between simultaneous and sequential decline in older adults, $t(23) = 3.18, p < .004$, but no difference in the younger adults, $t(23) = -.05, p = .963$. In the simultaneous condition there was no difference in scores between young and older adults $t(46) = .06, p = .953$. In the sequential condition younger adults had significantly higher scores than older adults $t(46) = 2.31, p < .05$ (See Fig 2.8).

**Fig 2.8:** Mean dual-task condition percentage compared to single task performance (Error bars represent Standard Error of the Mean)

**Relative Dual Task Score as a Percentage of Single Task Performance**

Discussion

This study aimed to assess the effects of verbal interference in young and older adults on memory tasks designed to tap separate components within the visuo-spatial
working memory system. It was hypothesised that younger adults would show no significant effect of verbal interference on either memory task. Older adults were expected to demonstrate a general effect of suppression, with a greater effect in a sequential memory task than in a simultaneous memory task.

There was a main effect of age group and a main effect of task type. The effect of age group supported the age-related declines in visual task performance demonstrated by Brockmole & Logie (2013). The effect of task type supports the fractionation of the visuospatial system outlined by Logie (1995) and demonstrated by Logie & Pearson (1997). The task type x age group interaction was characterised by older adults showing a greater similarity between maximum performance on the simultaneous and sequential tasks compared to that seen in younger adults. This supports the results of Beigneux et al. (2007) and could be taken to be evidence for a dedifferentiation of visuospatial abilities as outlined by Chen et al. (2002). It also reflects the decline in simultaneous VPT ability across the lifespan seen in Johnson et al. (2010).

The separate ANOVAs showed that both young and older adults retained the task type effect. Despite the increasing similarity between simultaneous and sequential task performance, the older adults were still demonstrating separable visual and spatial abilities. This is in line with the data seen by Park et al. (2002) suggesting that older adults demonstrate distinct, but highly interrelated working memory abilities. The single group ANOVA’s revealed an effect of interference condition in the older adults. This provided partial support for the hypothesis that there would be differential effects of interference between the age groups. Whilst this could be taken as support for the experimental hypothesis, the lack of interference x task type interaction left the data open to the interpretation that older adults were simply demonstrating a dual-task effect on both tasks that could have been induced with any interference task.

In order to further explore this possibility the relative decline from single to dual-task conditions in both memory tasks was calculated. This percentage decline was explored in order to see the magnitude of change on the same scale between young and older adults. Younger adults showed no effect of task type on relative decline. However, the older group demonstrated an interaction between decline and task type. The relative decline between single and dual task was far greater in the sequential task compared
to the simultaneous task. This suggested that older adults were more susceptible to verbal task interference in the sequential task than in the simultaneous task.

The data here suggests that the two components of visual working memory are still dissociable in older adults. Therefore there are still similarities in the mechanism of the visuospatial system between young and older adults. It is possible to say that older adults are susceptible to verbal task interference on both forms of visuospatial task, but this was not seen in the between groups ANOVA and may not be a particularly robust effect. However it does suggest that some element of alternative task performance appears in older adult task performance. It is not clear what form this mechanism takes. It is even possible that the changes in spatial task performance may not match that seen in visual task performance. The effect of verbal interference in the simultaneous task may be due to a reliance on an object naming ability (as demonstrated by Hartley et al., 2001, in young and older adults), the effect in the spatial task may be due to verbally rehearsing the pathway created by the presented information. Whilst both behaviours would lead to recruitment of the phonological loop, the recruitment of attention, or long-term memory knowledge would be very different.

The null hypothesis, as well as the dull hypothesis can be rejected. The main effect of age group, the effects of interference in older adults, and the presence of differential relative decline suggested that older adults experience verbal interference in visual memory tasks. This interference appears to involve the phonological loop and there is a slight difference in the level of interference depending on the nature of the visual task (simultaneous/sequential). However it is likely that there are large individual differences in how people approach tasks and that these might increase with age. What is clear is that the same visual systems exist, but they may be supplemented differently by different people of different ages. Logie (2011) suggests that when faced with a difficult task individuals will seek to perform the task in the best manner possible using whatever resources they have available. At this point it is appropriate to consider Cowan’s (1998; 2005) view that task performance is based on activated LTM. Each individual will have their own specific bank of knowledge, and this will surely affect task performance. It is imperative that the focus of research remains on understanding
how people perform tasks, rather than measuring the efficacy of tasks. Therefore future work within this thesis directs people towards performing tasks in a certain manner and assessing subsequent effects on performance. It is likely that tasks are measuring people doing, or attempting to do the task in the manner they wish, and that is what is causing differential interference effects between groups.

A recap of Chapter 2

Experiment 1 in this thesis attempted to replicate Brandimonte et al. (1992) in finding a positive effect of articulatory suppression on a mental imagery task in young and older adults. This positive effect was found in older adults with easy-to-name items. Older adults suffered a negative effect when presented with difficult-to-name items. Experiment 2 sought to investigate the double dissociation between verbal and visual memory stores at two different points in the lifespan. The classic dissociation with domain specific interference was replicated in younger adults, and in verbal task performance in older adults. However, visual task performance in older adults was equally susceptible to both visual and verbal interference. Experiment 3 assessed the effects of a verbal interference task on performance in simultaneous and sequential versions of the visual patterns task. Older adults showed a general effect of suppression on task performance, with a slightly stronger effect in the sequential task.

There is a clear distinction between the results of Experiment 1 and of Experiments 2 and 3. In Experiments 2 and 3 there was a clear negative effect of articulatory suppression on performance in visual memory tasks in older adults. Putting aside considerations of the level of executive or long-term memory involvement in task performance, this is clear evidence for some role of the phonological loop in aiding visual task performance in older adults. However the positive effect of suppression on older adult performance in easy-to-name shapes in Experiment 1 demonstrates that at least partially disabling the phonological loop can benefit older adult task performance.
In contrast, the introduction of suppression when the patterns were difficult-to-name led to a reduction in performance. It is likely that these differences arose due to the length of time that participants were required to maintain information in the three experiments. Experiments 2 and 3 required participants to maintain items for 10 seconds, and as such may have been reliant on rehearsal in a short-term working memory system. The participants in Experiment 1 would have been required to maintain information for 1 to 2 minutes. Recall did not begin until pattern sets had been displayed 3 times; as such this brings the study into the realms of a long-term memory task. Furthermore, Experiment 1 required participants to manipulate the presented items, the second two experiments required participants to reproduce what they had seen. It may be possible that older adults spontaneously employ the phonological loop when presented with visual information. In a short-term task where recreation of the presented information is needed, this method may be beneficial. In a longer-term task where a manipulation of the specific stimulus is needed (such as Experiment 1), then encoding the item and preventing verbal rehearsal may maintain the integrity of the item. That is not to say that a long-term memory will not need a verbal label. Long-term memories are affected by semantic information (Baddeley, 1966b) and the demands of articulatory suppression would not prevent a simple descriptive label being assigned to a stimulus, especially if the stimulus were ‘easy-to-name’. This may be the explanation for the negative effect of suppression in the difficult-to-name condition for the older adults. If a simple, easy to recall semantic association cannot be made under suppression due to the inherent qualities of the shape presented, and then a negative effect of suppression, due to the prevention of rehearsal would be likely.

Whilst there has been a demonstration of differential effects of articulatory suppression between age groups in the 3 experiments seen here, the scope and difference between the experimental tasks makes specific predictions difficult. It appears that activation (or lack of inhibition) of the phonological loop is spontaneous in older adults, this is commensurate with Hartley et al (2001) and Chen et al. (2002). Despite this, there remains a separable visuo-spatial working memory architecture that is capable of performing tasks, whether the tasks employ the visual cache or in the inner scribe (Park et al., 2002; Logie, 2011). The overall pattern of data is commensurate with the
Scaffolding Theory of Park & Reuter-Lorenz (2009) in that there appears to be compensatory recruitment in the face of visual decline in older adults, yet this recruitment does not always benefit, and does not appear to improve task performance beyond that of the original structures employed in younger adults. More information regarding the specific situations in which task differences arise is needed in order to understand the nature of differential decline in older adults.
Chapter 3

The general decline of working memory performance in aging is well-established (Perfect & Maylor, 2000; Park et al., 2002; Salthouse & Meinz, 1995). However, as outlined by the ‘Dull Hypothesis’ (Perfect & Maylor, 2000), to simply state that decline in memory performance with aging is linear, and simply that older adults exhibit cognitive deficits, does not lead to progress in understanding the mechanisms underlying cognitive aging (Jost, Bryck, Vogel & Mayr, 2011; Perfect & Maylor, 2000; Salthouse, 2000). It is unclear, especially in the visual domain, if standard working memory tasks measure the same constructs across the lifespan (Chen et al., 2002; Johnson et al., 2010; See also, data presented in Experiments 1, 2 and 3 of this thesis). It is also evident that formerly specialized components such as memory for static, visual information and memory for dynamic, spatial information become less separable with age (Chen et al., 2002). Prior to introducing the methodology for Experiments 4 and 5 there will be a brief recap of the concepts of working memory and ageing that are pertinent to these studies.

Visual and spatial working memory as separable components

The Multiple Component Model (Baddeley, 1983; 1986; 2000; Logie, 2011) describes two, domain-specific memory stores, separately concerned with phonological and visuospatial information, and an amodal central executive (Later versions incorporate a multidimensional episodic buffer). The visual store of the Multiple Component Model is separable into specialized components operating on visual and spatial material (Della Sala et al., 1999; Logie & Pearson, 1997). The visual cache is a passive store for simultaneous, static visual images. The inner scribe is an active store for the rehearsal and maintenance of spatial, sequential, or dynamic information (Darling, Della Sala, & Logie, 2007; Logie, 1995). Selective interference paradigms have demonstrated a dissociation between these two temporary stores, which develops at 8 to 10 years of age (Logie & Pearson, 1997; Pickering et al. 2001). Items such as irrelevant pictures have been shown to interfere with maintenance of simultaneous
information in the visual cache, whereas spatial tapping, and other movement tasks, have been shown to interfere with recall of information stored in the inner scribe (Della Sala et al., 1999; Logie & Pearson, 1997; Quinn & McConnell, 1996).

Simultaneous and spatio-sequentially presented information leads to differential recruitment of central executive processes. Baddeley, Cocchini, Della Sala, Logie and Spinnler (1999) demonstrated that spatial information required a greater use of executive function than a verbal task. Rudkin et al. (2007) demonstrated that participants experienced greater interference from random digit generation when performing a spatio-sequential memory task compared to performing a visual task with simultaneous presentation. As such spatio-sequential tasks were suggested to involve executive resources to a greater extent than simultaneous tasks. Further differentiation in spatio-sequential tasks arises from the manner in which information is presented. Sequential patterns where the to-be-remembered information crosses paths are more likely to demonstrate serial position errors than those that do not. Path crossing has been shown to lead to encoding, but not specifically rehearsal deficits. It is possible that individuals are using one, or more of three methods, either through encoding information as a single simultaneous pattern, as a collection of chunked items, or as a sequential path, depending on the most beneficial encoding method (Parmentier, Elford, & Mayberry, 2005; Parmentier & Andres, 2006).

**Effects of ageing on visual and spatial working memory**

Beigneux et al. (2007) demonstrated a pronounced age related effect in visual, rather than spatial memory tasks when comparing older adults to younger adults. (See also Brown et al., 2012). Conversely, Oosterman, Morel, Meijer, Buvens, Kessels, and Postma (2011) found there was a greater age-related decline in spatial memory tasks compared to visual memory tasks. It is possible that the conflicting results from these studies arise from the method of measurement used. The Beigneux et al. study assessed memory recall capacity, whereas Oosterman and colleagues tested participants on the percentage of correctly recalled items on a 5x5 grid. When comparing young and older adults’ performance on memory tasks, the maximum memory performance of the
individual, regardless of their age, will have an effect on the manner in which the individual performs a task. Logie et al. (2007) demonstrated this effect, by showing no specific dual-tasking deficit in older adults, once the demands of the memory task had been titrated to the abilities of the individual. It is possible that the Oosterman et al. study was testing older adults near to the limits of their memory capacity, whereas the task was not reaching the upper limits of the younger adults’ abilities. This may have denied younger adults the chance to demonstrate increased performance in the simultaneous task.

When considering maximum memory capacity, older adults show a smaller discrepancy between performance on simultaneous and sequential visuospatial tasks than younger adults do. It may be possible that older adults perform simultaneous and spatio-sequential tasks using primarily an overlapping, more generalized mechanism, whereas younger adults use the specialized stores outlined in the multiple-component model. As has been seen in the age-related variation in working memory section of this thesis, as well as in Experiments 1, 2 and 3, the possibility of this dedifferentiation across the adult lifespan, as both a behavioural and neuronal change, is a common feature of cognitive ageing research (Hartley et al., 2001; Park et al., 2010. For example, Chen et al. (2002) used principle components analysis to demonstrate that older adults’ performance on visual and spatial tasks loaded on a generalized factor, in contrast to younger adults, who demonstrated a two-factor solution involving the general factor as well as a second one that was related to use of either ventral (visual) or dorsal (spatial) processing streams.

**Cross-Modal working memory performance**

Whilst working memory models such as the MCM posit a distinction between domain specific stores, it is suggested that there are conditions in which multi-modal encoding of information can lead to, or is necessary for improved task performance (Logie, 2011). Within the MCM it is possible that multi-dimensional representations are held in the episodic buffer (Baddeley, 2000), alternatively, cross-modal encoding may afford the activation of long-term memories or previously held knowledge relating to
the presented information, which may be of benefit when attempting to recall items (Cowan, 2005). Multi-dimensional representations of visually presented verbal information have been demonstrated in Darling and colleagues’ (2010, 2012) studies on visuospatial bootstrapping. To recap, participants show improved digit spans when digits are presented in a familiar telephone keypad layout, compared to when they are presented from left-to-right, or in an unfamiliar layout. This suggests an interface through which long term knowledge, possibly held in the episodic buffer can provide support for verbal and spatial working memory systems (Darling & Havelka, 2010; Darling et al., 2012). Saito et al. (2008) demonstrated an automatic activation of multi-dimensional representations of visually presented verbal stimuli by showing a visual similarity effect on recall of Japanese characters that were visually similar, but phonologically dissimilar. The episodic buffer may play an important role in the amalgamation of information from these separate stores (Allen et al., 2006; Baddeley et al., 2011). This is an interpretation within the MCM that allows for conclusions that are in line with the suggestions of Cowan’s (2005) EPM, as well as the PM/SM distinction outlined by Unsworth & Engle (2006). It is commensurate with a view of working memory as a single system, with many separable components, organised by the individual’s control of attention, or executive abilities that seeks the most parsimonious method to maintain information. Whilst there are domain specific structures, this does not preclude the use of more than one structure to carry out any given task.

As was discussed in the ‘Variation in working memory’ section of the introductory chapter, there is evidence for multi-dimensional encoding in predominantly visual tasks. To recap, Brown et al. (2006) demonstrated a positive effect of the availability of verbal coding in the visual patterns task. Easy-to-name (ETN) and hard-to-name (HTN) pattern sets based on the availability of verbal labels were created through a pilot study asking participants to provide verbal labels for patterns from the Della Sala et al. (1999) version of the VPT. A follow-up experiment was then used to assess the effect of nameability, using a standard VPT procedure with a 10 second maintenance period. Visual working memory span was reliably increased in the ETN pattern set. The only functional difference between the pattern sets was the level of verbal labels.
that could be applied to them, suggesting some form of dual-coding, or the activation of previously held knowledge was being used where available.

The Brown and Wesley (2013) investigations into the nature of this multi-dimensional encoding used the same stimuli to assess the memory processes used by young adults during performance of the VPT. Separate groups undertook the ETN and HTN versions of the task, with or without articulatory suppression. Participants then undertook a questionnaire assessing how they performed the VPT described above (e.g., visually, verbally, or by a combining strategy). Because articulatory suppression did not remove the benefit of the ETN patterns, it was argued that the underlying resource was unlikely to be a purely verbal recoding process within the phonological loop. However, actively combining verbal and visual strategies, and automatic activation of semantic knowledge (e.g. knowing that a given pattern resembles a particular animal), both appeared to be related to increased memory capacity. A second experiment assessed the effect of a central executive task (random spatial tapping) on task performance. Relative to control and repetitive spatial tapping tasks, only the requirement to use central executive resources in the random tapping task was found to remove the benefit of the ETN pattern set. This indicated that central executive resources are involved in cross-modal strategy use, and this may be via the episodic buffer component of working memory. Again, the results of Brown and colleagues are reconcilable with the possibility of an adaptive working memory system where individuals can perform the same memory task in a number of differing ways. We have seen that self-report of strategies can account for experimental patterns of performance, but can be independent of span (Logie et al., 1996) suggesting that individuals approach tasks in a manner that suits them, but that this is not necessarily connected with their level of performance. This is not entirely in line with the results of Brown and Wesley, who found that those who reported ‘Combining Strategies’ demonstrated generally higher span scores across both versions of the VPT. However, both studies are compatible with a view of a high level of individual differences within working memory performance that differ from the psychometric view of differences based on general intelligence.
Data from studies assessing multi-dimensional representations of information are complex and suggest that cross-modal encoding is not always of benefit to task performance. Brandimonte et al., (1992) found that participants displayed improvements in identifying hidden letters in a mental image rotation task using easy to label objects when performing articulatory suppression. However, Experiment 1 in this thesis fails to replicate these findings, finding that young (18-25) adults suffer a negative effect on performance under articulatory suppression, whilst older adults (60-75) demonstrate the benefit of articulatory suppression (For full explanation and discussion, see Chapter 2, Experiment 1). These age-related differences in Experiment 1 suggest that the mechanisms by which young and older adults perform memory tasks are not always identical. This will be explored in greater detail in the next section.

Changes in cross-modal performance with age

In experiments 1, 2 and 3, the research emphasis was on identifying differential patterns of interference between young and older adults (Refer to Chapter 2 for a full description). The general findings of these 3 experiments suggested that older adults (60-75) suffered from both verbal, as well as visuospatial interference in some, but not all visuospatial tasks. The aim of the research within this section is to establish the presence and possible differences in cross-modal encoding at different points in the lifespan. As explained in the ‘Introduction to Cognitive Ageing’ section of the opening chapter, ‘Scaffolding’ (STAC; Park & Reuter-Lorenz, 2009) is posited to be the recruitment of compensatory, generalized neural circuitry in order to support performance of cognitive tasks. Whilst performance in numerous memory tasks declines with age, functional brain activity may increase, particularly regarding bilaterality and frontal activation of the dorsolateral prefrontal cortex (Reuter-Lorenz et al., 1999). In younger adults, increasing task difficulty has been positively associated with bilateral activation (Banich, 1998). Older adults may be demonstrating this pattern of performance, but at a lower level of task difficulty. In its simplest terms scaffolding theory suggests that young adults’ neurological response to an extrinsic challenge, such as task difficulty, is mirrored in the response to an intrinsic challenge, such as aging, in older adults.
Indeed, cross-sectional large scale data from the BBC Memory study (Johnson et al. 2010; Logie & Maylor, 2009) provides evidence for more generalized task performance with increasing age. A single factor was found to explain performance in five working memory (2 verbal and 3 visual) tasks across age groups from 18-80 years. However, measurement invariance was only obtainable between 18-35 years; outside of this age bracket it was not possible. Trends in the residual variance differed across age groups. Specifically, visual pattern span, the task used in the present research, demonstrated a decrease in residual variance and performance with age, which was attributed to a possible increasing and unreliable reliance on a general working memory capacity to carry out the task. It was concluded that the range of domain-specific resources change with different age-related trajectories;

The differences in measurement variance suggest that, not only do relatively specific abilities change in different ways with age, but people make use of their general/specific working memory capacities in different ways depending on age and developmental experience. (Johnson et al., p526, 2010).

It is evident that older adults may increase their reliance on cross-modal encoding, but this may not necessarily improve performance on a task. Logie et al. (2007) demonstrated effective dual-tasking in older adults, but this was tempered by an increase in reaction times in the secondary task. In fact, it is even possible that older adults could tend to select strategies that are inappropriate to task performance, for example by relying solely on verbalisation. This makes sense when considering that verbal knowledge remains stable throughout the adult lifespan, and may even continue to increase until late older age (Park et al., 2002; Johnson et al., 2010). This verbalisation could take the form of pure phonological rehearsal, or it could be a means to implement strategies such as chunking, or labelling.

To summarize, visuospatial working memory is separable into further specialized components (Della Sala et al., 1999; Logie & Pearson, 1997; Quinn & McConnell, 1996). However, these components, or the extent of differential performance between them, may become less separable with age (Beigneux et al., 2007; Chen et al., 2002).
Cross-modal encoding can benefit younger adults in both the visual and verbal domains (Brown et al. 2006; Brown & Wesley, 2013; Darling & Havelka, 2010; Saito et al., 2008). However, cross-modal encoding, especially in the visual domain may occur more often, and at lower levels of task difficulty in older adults. In the present research, the Brown et al. (2006) ETN and HTN pattern sets were used to assess a) the separability of visual and spatial task performance in young and older adults, and b) whether age influences the extent of cross-modal processing in visuospatial working memory (See Appendix B.1 for typical examples of ETN/HTN pattern sets). It was hypothesised that visual and spatial working memory would be less specialized in older age, as indicated by (Johnson et al., 2010), and that older adults, due to decreased specialized capacity, will incorporate more cross-modal processing in working memory, as evidenced by Chen et al. (2002).

**Experiment 4**

In the first of a series of two experiments, the Brown et al. (2006) nameability effect was analysed in young and older groups, using both simultaneous and sequential-ordered presentation. At presentation in the sequential task, squares from each pattern would always be presented from left-to-right, and top-to-bottom, in a manner akin to reading. The dependent measures were capacity (span) and percentage decline from simultaneous to sequential encoding conditions.

Using simultaneous presentation, Brown et al. (2006) and Brown and Wesley (2013) demonstrated a nameability effect for both young (18-30) and older (65+) adults. This was expected to be replicated in the current simultaneous version of the task. The exact mechanisms which afford the ‘nameability benefit’ to ETN patterns in the simultaneous version of the VPT are unclear, however, the results of Brown and Wesley (2013) led to the suggestion that participants either access semantic information, or actively maintain a multimodal representation of the patterns in the episodic buffer. There is no evidence from the previous experiments in this thesis, or the work of Brown and colleagues which would suggest that young and older adults
would not demonstrate this pattern of performance on the simultaneous task. The results of Experiment 3, where older adults demonstrated a negative effect of articulatory suppression on a sequential spatial task suggest that the mechanisms of performance in sequential tasks differ between young and older adults. This, as well as the age-related decline in visuospatial abilities (Logie & Maylor, 2009) led to the hypothesis that older adults may benefit from the availability of multi-dimensional encoding in a sequential task where the method of presentation would lend itself to the building of an overall image of the presented information. Furthermore, the age related dedifferentiation of visuo-spatial abilities outlined by Chen et al. (2002) would suggest that older adults would demonstrate similar patterns of performance between differing visual memory tasks. Therefore, it was predicted that if there were a benefit of nameability for older adults in the simultaneous task, then there would be a benefit of nameability in the sequential-ordered task.

Sequential-ordered presentation was chosen as Lecerf and De Ribaupierre (2005) found performance on a sequential visual task was better when the presentation of patterns was ordered, compared to performance on a task with randomised presentation. It is suggested that performance in a serial order spatio-sequential recall task is based upon the ability to trace the movement of the to-be-remembered information in order to build a static representation of the pattern created (Parmentier et al., 2005). The two methods of presentation in this experiment lend themselves to the use of chunking, or verbal encoding that may be leading to the Brown et al. (2006) nameability effect. If older adults are performing visual and spatial tasks in the same manner then it is likely that the availability of verbal encoding in both methods of presentation will lead to matching results between presentation types. This could be due to verbally recoding the visually presented information using the phonological loop, although the work of Brown and Wesley (2013) suggests that this is unlikely. Brown and Wesley suggest that the allocation of central executive resources is key to a nameability benefit. The allocation of these resources may take (actively maintaining multimodal representations of presented information in the episodic buffer. This is a view that corroborates with the concept of STAC, which suggests that there is a greater
reliance on semantic information in older adults compared to younger adults (Park & Reuter-Lorenz, 2009)

As participants are being measured up to their maximum ability in all conditions it is expected that results will match the patterns of behaviour seen by Beigneux et al. (2007), where there will be a greater age-related decline in simultaneous compared with sequential task performance.

Methods

Participants
Two groups of participants took part in the study. Twenty-four young adults (11 females, 13 males), aged 18-25 years ($M = 21.3$, $SD = 1.8$), and 24 healthy older adults (15 females, 9 males), aged 60-75 years ($M = 65.6$, $SD = 3.6$). Education level was measured on a 4 point scale (1 = Did not finish high school, 2 = Finished high school, 3 = Undergraduate degree, 4 = Postgraduate degree). There was no difference in education levels between groups (Young mean = 2.9, $SD = .7$, Older mean = 2.8 $SD = .60$) $t(46) = .829, p = .412$). All older adults adequately completed the Mini Mental State Examination (MMSE; Folstein et al., 1975), which was used to screen for unhealthy cognitive decline ($M = 29.6$ $SD = .60$, max 30, all scores ≥27). Younger participants were recruited through a University of Edinburgh part-time vacancy website or were taking part for course credit. Older adults were recruited through the University of Edinburgh volunteer panel. Other than those taking part for course credit, participants were paid £5 for their time. All participants reported normal or corrected-to-normal vision.
Materials
Participants were presented with ETN and HTN pattern sets developed by Brown et al. (2006). Patterns were presented on a Dell 17inch touchscreen monitor. Each individual square within a pattern was 150x150 pixels (therefore a 4x4 pattern grid measured 600x600 pixels). Participants entered responses by simply touching the screen (See Appendix B.1). A stylus was provided for those who had difficulty in extending digits to press the screen. The experiment was run using E-Prime 2.0 software and coded using E-Basic script (Psychology Software tools inc).

Design
The study took the form of a 2 (age: young and older) x 2 (presentation type: simultaneous and sequential) x 2 (nameability: ETN and HTN) mixed design, with age as the between group variable. All participants therefore completed 4 conditions, involving simultaneous and sequential-ordered presentation of ETN and HTN shapes. Span measures of performance, measuring the mean level of complexity achieved, were taken.

Procedure
Participants were tested in an experiment laboratory within the University of Edinburgh Psychology department. Older adults initially took the MMSE. All participants were given two practice tasks, one simultaneous and one sequential-ordered at the lowest level of complexity (4 squares to remember). Once they had achieved a satisfactory performance on these tasks (defined as correctly recalling at least 2 out of 3 patterns, the level of performance that would be required in order to progress in the task) they were asked to take part in the four experimental conditions. All conditions were completely counterbalanced. The study typically took between 45 minutes to an hour to complete.

In both the simultaneous and sequential tasks participants were presented with an instruction screen informing them of the nature of the study. Participants were then told to touch the screen when they were ready to continue. In the simultaneous task the pattern presentations began with a fixation cross for 500ms, followed by
presentation of the to-be-remembered information for 3000ms. Participants then saw a blank blue screen for 10000ms. After this a blank version of the presentation grid was shown for an unlimited time. Participants responded by touching the cells of the blank template that they believed to have been black. Responses were deemed complete when the participants had indicated all the squares that they thought had been present at presentation. Participants could only select each square once, and were unable to delete incorrect choices. This step was taken in order to prevent people changing the pattern until it was recognised from the presentation. Participants could only select as many squares as had been originally presented. Once the requisite number of squares had been entered, the next trial was presented. Participants were informed at the beginning of every presentation level of the size of the grid, and how many squares were to be remembered.

The sequential task followed a similar procedure. After a 500ms fixation cross participants were presented with each square from the pattern for 1000ms. After the final square was presented a blank blue screen appeared for 10000ms, followed by a blank grid for an unlimited time. Participants were instructed to recall the pattern they saw in the specific order it was presented. As with the simultaneous task, participants were unable to delete incorrect choices.

Simultaneous and sequential tasks began with an 8 square grid, with 4 squares to recall. There were 3 patterns at each level of complexity. After 3 grid presentations participants would be instructed that they were moving to the next level. Each level increased the grid size by 2 squares and the memory load by 1 square. Both simultaneous and sequential tasks ranged from 4 to 15 squares to remember. Each condition stopped when a participant was unable to correctly recall 2 out of the 3 possible patterns at any level. Span score was taken as the mean pattern size in the last 3 correctly recalled patterns (e.g. 1 correct pattern at 10 squares to remember and 2 correct at 9 to remember equals a span of 9.67).
Results

The data resulting from each condition are presented in fig. 3.3. A 2(age group: young or older) x 2 (presentation type: simultaneous and sequential) x 2 (nameability: ETN and HTN) mixed ANOVA, with age as the between subjects variable, was carried out on the maximal span scores. There were significant main effects of age group, $F(1,46) = 36.43, p < .001, \eta^2_p = .44$, presentation type, $F(1,46) = 260.26, p < .001, \eta^2_p = .85$, and nameability, $F(1,46) = 9.37, p < .004, \eta^2_p = .17$. Overall, performance was superior within the simultaneous encoding condition, and with the ETN pattern set. However, there was also a significant presentation type x age group interaction, $F(1,46) = 24.59, p < .001, \eta^2_p = .35$. Bonferroni adjusted t-tests showed that in the young group there was a significant difference between performance in the simultaneous condition ($M = 9.52, SD = 1.67$) compared to the Sequential condition ($M = 6.05, SD = 1.01$), $t(23) = 12.68, p < .002$. In the older group there was also a significant difference between performance in the simultaneous condition ($M = 6.76, SD = 1.14$) compared to the Sequential condition ($M = 4.92, SD = 1.09$) $t(23) = 10.06, p < .002$. However the mean difference between simultaneous and sequential performance in the younger adults ($M = 3.47, SD = 1.34$) was greater than in the older group ($M = 1.84, SD = .89$) $t(46) = 4.96, p < .001$. There was a marginally significant 3-way interaction between nameability, presentation type and age group, $F(1,46) = 3.85, p = .056, \eta^2_p = .077$.

Fig 3.1: Mean scores on VPT for both age groups with simultaneous and sequential-ordered presentation (Error bars represent Standard Error of the Mean)
Separate 2 x 2 repeated-measures ANOVAs were therefore performed within each age group. In the younger group there was a significant effect of presentation type, $F(1,23) = 160.81, p < .001, \eta^2_p = .88$, and a presentation type x nameability interaction, $F(1,23) = 6.92, p < .015, \eta^2_p = .23$. Bonferroni adjusted t-tests showed there was significant difference in performance on the ETN patterns ($M = 10.03, SD = 1.89$) compared to the HTN patterns ($M = 9.01, SD = 2.03$) in the simultaneous condition, $t(23) = 2.42, p < .05$. In the sequential condition there was no significant difference between performance on the ETN ($M = 5.97, SD = 1.23$) and HTN ($M = 6.13, SD = 1.17$) conditions, $t(23) = -.625, p < .538$. On the ETN pattern sets there was a significant difference between performance in the simultaneous task compared to the sequential task, $t(23) = 14.03, p < .001$. In the HTN pattern set there was also a significant difference in performance on the simultaneous pattern set compared to the sequential pattern set, $t(23) = 7.04, p < .001$. Thus, the nameability effect existed only in the simultaneous presentation condition for the younger group. To confirm, there was no main effect of nameability in the younger adults, $F(1,23) = 2.46, p = .131$.

In the older group there was a main effect of presentation type, $F(1,23) = 101.20, p < .001, \eta^2_p = .82$, with higher capacity in the simultaneous condition (mean diff = 1.84), and a main effect of nameability, $F(1,23) = 7.784, p < .01, \eta^2_p = .25$, with higher scores in the ETN condition (mean diff = .72). There was no presentation type x interference interaction within the older adults ($F < 1$).

**Percentage Decline**

To compare between age-group performances on each presentation type, one-way ANOVAs were conducted on the percentage change from HTN to ETN pattern sets between the two age groups. There was no significant difference in ETN/HTN change between age groups in the simultaneous task, $F(1,46) = .01, p = .994$. There was a significant difference in ETN/HTN change between age groups in the sequential task, $F(1,46)= 4.144, p < .05$. 

132
Discussion

The purpose of this experiment was to assess the cognitive mechanisms contributing to visuo-spatial working memory task performance in young and older adults. Specifically, the aim was to determine whether there are more general experimental effects between tasks in older adults than there are in younger adults. A lack of task interactions would indicate more generalised performance between tasks. A greater benefit of semantic input, as indicated by a nameability effect, would be indicative of more widespread reliance on generalised resources, and evidence of scaffolding in working memory.

There were significant main effects of nameability, age group, and presentation type. The main effect of nameability replicates the findings of Brown et al. (2006) and shows that individuals can supplement their performance on a visual working memory task with executive recruitment, possibly by increasing semantic awareness or the availability of suitable long-term memory representations (Brown & Wesley, 2013). It is very unlikely that participants solely use a verbal encoding and rehearsal strategy, as Brown et al., showed that the number of labels that can be applied to patterns does not increase linearly through the levels of complexity. Specifically, at the higher levels of simultaneous presentation, there is too much information to allow complete verbal encoding. A more parsimonious explanation would be to suggest that larger patterns are broken down into recognisable chunks. This is compatible with the increasing number of available labels for patterns with increasing set size seen in Brown et al. (2006).

The main effect of age-group demonstrates that, as would be expected, younger adults possess a higher visuo-spatial working memory capacity, compared to older adults. This reflects the general age-related cognitive declines previously observed (Park et al., 2002, Park & Reuter-Lorenz, 2009), but also supports previous evidence of specific age-related visual working memory deficits (e.g., Beigneux et al., 2007; Brown et al., 2012; Bruyer & Scailquin, 1999; Leonards, Ibanez, & Giannakopoulos, 2002; Myerson et al., 1999).
The main effect of presentation type demonstrated higher scores in the simultaneous task compared to the sequential task in both age groups, replicating the findings of Lecerf and De Ribauypierre (2005) and Beigneux et al. (2007). The interaction between presentation type and age group further replicates the results of Beigneux et al. by demonstrating a greater decline between simultaneous and sequential presentation in young, compared to older adults.

As hypothesized, the marginal three-way interaction suggests that the availability of verbal coding and, thus, the availability of semantic elaboration affects young and older adults differently, depending on the method of presentation. In the older adults, the main effect of nameability, and the lack of presentation type x nameability interaction suggest that these participants may use the same mechanisms or strategies to perform both the simultaneous and sequential tasks. It is possible that performing simultaneous and sequential tasks in a similar manner could be an adaptive response to the declines in visuo-spatial working memory performance seen in older adults (Johnson et al., 2010; Park et al., 2002).

Considering the younger adult data only, the lack of nameability effect, coupled with the main effect of presentation type, and the presentation type x nameability interaction in the younger group is consistent with the hypothesis that younger adults perform simultaneous (visual) and sequential (spatial) tasks in a qualitatively different manner (Logie, 2011). We have replicated the findings of Brown et al. (2006) by demonstrating a benefit associated with the availability of verbal encoding, but we have extended this to show that the effect exists only with the simultaneous task. This further highlights a dissociation between visual and spatial working memory processes.

A simple explanation for the results seen here would be that it is the nameability of the shapes, or the semantic activation afforded by them that causes any differences in performance. Other factors, however, such as the method of presentation may be a determining factor. The sequential task involved the use of an ordered path, where
black squares would always be presented from left-to-right, top-to-bottom, in the same manner as standard reading. Shapes that are easier to name in a simultaneous task may lend to themselves to ‘chunking’ in a sequential ordered presentation. If older adults are more likely to use the same mechanism in each task, applying the simple rule of ‘remember the squares left-to-right’ may benefit performance in the ETN more than the HTN condition regardless of the presentation method. That is not to say that young adults may not also be performing the tasks in this manner. Scaffolding theory (Park and Reuter-Lorenz, 2009) suggests that the performance of older adults is akin to those of younger adults when performing difficult tasks. It is therefore possible that the both age groups were attempting to employ multi-dimensional representations of the sequential information in both the ETN and HTN conditions, the younger group may have been more successful than the older adults and therefore not shown a benefit of ETN pattern set. This possibility is supported by the Rudkin et al. (2007) findings which suggested contribution of central executive resources when performing a spatio-sequential memory task for younger adults. A sequential presentation that does not follow a particular order may increase the difficulty with which participants can form either to-be-remembered pathways, or recognisable chunks of information.

While these results support the hypothesis that patterns of performance will differ between young and older adults, it is unclear whether these differences reflect the use of different mechanisms between age groups, or they are a function of the methods of presentation used. Experiment five was designed to address this question.

**Experiment 5**

Experiment 5 aimed to replicate Experiment 4 by again looking at the effects of age group, nameability, and presentation type on visuo-spatial working memory performance. However, in this case the pattern of presentation in the sequential condition was randomised; meaning squares from each pattern appeared at random locations within the pattern grid, rather than in a fixed order as in Experiment 4. Lecerf and De Ribaupierre (2005) and Parmentier et al. (2005) suggested that sequential
randomised presentation increases the likelihood of ‘crossings’, which are hypothesized to disrupt path-following, or pattern creation in movement sequences. If older adults were attempting to perform the sequential task in the same manner as the simultaneous task, then the randomised presentation of squares is likely to disrupt the nameability effect. A replication of the results from Experiment 4 was hypothesised; specifically, a benefit of ETN patterns over HTN patterns for both young and old in the simultaneous task, and a greater decline from simultaneous to sequential presentation in young compared to older adults. However, due to the randomised presentation of squares in the sequential task, no nameability effect is expected in either group within this version of the task.

Methods

Participants
Two groups of participants, who had not participated in Experiment 4, contributed to the study. There were 24 young adults (16 females, 8 males), aged 18-25 years (M = 20.71, SD = 2.01), and 24 older adults (16 females, 8 males), aged 60-75 years (M = 67.67, SD = 3.04). There was no difference in education levels between groups (young M = 2.79, SD = .78, older M = 3.04 SD = .55; t (46) = -1.28, p = .21). There was no difference between the mean ages and the mean education levels of the participants across the two experiments (Age: young: t (46) = 1.13, p = .27), older: t (46) = -1.88, p = .07) (education level: young: t (46) = .56, p = .58, older: t (46) = -1.74, p = .09). All older adults adequately completed the MMSE (Folstein et al., 1975; M = 29.54 SD = .66, max 30, all scores ≥ 27). There was no difference between MMSE scores in older adults between experiments 1 and 2, t (46) = .37, p = .71. Participants were recruited using the same methods and remunerations as in Experiment 4.

Materials, Design, and Procedure
The experimental stimuli, software, and hardware from Experiment 4 were used. The simultaneous task was the same as in Experiment 4. The sequential task, however, now involved the presentation of each individual square from each pattern in a randomised, rather than fixed, order. Random orders of presentation were derived using a random
number generator and were fixed for all participants (Lecerf & De Ribaupierre, 2005). All tasks were counterbalanced. The procedure followed the methods described for Experiment 4.

**Results**

A 2 (age: young or older) x 2 (presentation type: simultaneous and sequential) x 2 (nameability: ETN and HTN) mixed ANOVA, with age as the between subjects variable, was performed on participants’ span scores. There were significant main effects of age, $F(1,46) = 65.52, p < .001, \eta^2_p = .59$ and presentation type, $F(1,46) = 447.59, p < .001, \eta^2_p = .91$, with superior performance within simultaneous presentation. There was no main effect of nameability, $F < 1$. There was, however, a significant presentation type x age group interaction, $F(1,46) = 15.51, p < .001, \eta^2_p = .25$. Bonferroni adjusted t-tests showed that in the young group there was a significant difference between performance in the simultaneous condition ($M = 10.04, SD = 1.41$) compared to the Sequential condition ($M = 5.17, SD = .60$) $t(23) = 16.32, p < .002$. In the older group there was also a significant difference between performance in the simultaneous condition ($M = 7.32, SD = 1.09$) compared to the Sequential condition ($M = 3.98, SD = 1.05$) $t(23) = 13.46, p < .002$. However, the mean difference between simultaneous and sequential performance in the younger adults ($M = 4.87, SD = 1.46$) was greater than in the older group ($M = 3.34, SD = .1.22$) $t(46) = 3.94, p < .001$. There was no age group x presentation type x nameability interaction $F(1,46) = .876, p = .35, \eta^2_p = .019$.

**Fig 3.2:** Mean VPT scores with simultaneous and sequential-randomised presentation (error bars represent the Standard Error of the Mean)
Due to the pattern of results seen in Experiment 4 separate within-group ANOVAs were then conducted. In the young group there was a main effect of presentation type, $F(1,23) = 266.47, p < .001, \eta^2_p = .92$, and a presentation type x nameability interaction, with a nameability effect only in the simultaneous condition, $F(1,23) = 9.801, p < .005, \eta^2_p = .30$. There was no main effect of nameability, $F < 1$.

In the older group there was a main effect of presentation type, $F(1,23) = 181.14, p < .001, \eta^2_p = .89$, with higher scores in the simultaneous task, but no effect of nameability, $F < 1$, and no presentation type x nameability interaction, $F(1,23) = 2.08, p = .163, \eta^2_p = .08$.

**Percentage Decline**

There were no differences in HTN to ETN percentage change between age groups in either the simultaneous, $F(1,46) = .01, p = .995$, or the sequential task, $F(1,46) = 1.20, p = .279$.

**Discussion**

As with Experiment 4, the purpose of this experiment was to assess the cognitive mechanisms contributing to visuo-spatial working memory task performance in young and older adults and to assess the possibility of generalised task performance in older adults when completing simultaneous and sequentially presented visual patterns tasks. The key, and only difference from Experiment 4 was the manipulation of the sequential task presentation method. In Experiment 4 sequential information was presented in a pre-determined order (Left-to-right, top-to-bottom), in the current experiment the presentation path was randomised so as to allow sequential pathways which ‘crossed’ and moved in unpredictable patterns. These randomised paths were fixed for all participants.
For the younger group Experiment 5 replicated the main effects of age, presentation type, and the age x presentation type interaction seen in Experiment 4. This also provides further support for the findings of Beigneux et al. (2007), that age effects are greater for visual (static) relative to spatial (sequential) working memory. While the overall effect of nameability observed in Experiment 4 was not replicated, within group ANOVAs showed that younger adults displayed the same main effect of presentation type, and the presentation type x nameability interaction seen in the first experiment. Specifically, the nameability benefit was observed in the simultaneous, but not in the sequential condition, as hypothesised.

In the older group, both a main effect of presentation type, and a lack of presentation type x nameability interaction, replicated the results from Experiment 4. Crucially, however, when measuring performance using span measures older adults did not demonstrate the nameability effect seen in the first experiment. Conversely the analyses of percentage declines in the simultaneous task replicated the findings of Experiment 4, with no difference between age groups. However, where there had been a difference between age groups when looking at sequential percentage decline in Experiment 4, there is no difference in Experiment 5. The removal of ordered sequential presentation removed the difference in performance between young and older adults in the sequential task. It is possible that the inherent difficulty in remembering a sequential presentation that followed a randomised path removed attempts (or at least successful attempts) at a strategic approach, or link to long-term memory in either age group, therefore removing any opportunity for there to be differences in decline between pattern sets.

There are therefore two key findings to be taken from Experiment 5. The first is that whilst there is a complete replication of all patterns of performance from Experiment 4 in the younger group, the difference in presentation format in the sequential presentation condition (ordered to randomised) brought about a change from an overall nameability effect, to no nameability effect in either condition for the older group. The potential for this pattern of effects was evident when considering previous theory and
empirical data (Lecerf & De Ribaupierre, 2005; Parmentier et al., 2005). It appears that the introduction of a randomised sequential task has had a deleterious effect on the benefit of nameability in the simultaneous task in older adults. The analysis of ETN/HTN percentage decline in the simultaneous task showed no age difference between groups with both groups showing a significant decline in HTN pattern set performance. This was despite there being an overall loss of the nameability effect in the older adults. This suggests that, whilst the simultaneous nameability benefit had been weakened in older adults (possibly as a result of the loss of nameability effect in the sequential task), it was not sufficient to significantly change the patterns of performance compared to the younger adults.

The second key finding is that younger adults have demonstrated an interaction between presentation type and nameability, with a nameability effect in the simultaneous, but not the sequential tasks in both experiments. Conversely, older adults have not demonstrated this interaction in either task. There is a main effect of nameability in Experiment 4 with span measures in the older adults that is not present in in Experiment 5. Logie (1995) suggests that younger adults adopt different mechanisms for performing either simultaneous or sequential presented visuospatial tasks, and it is likely that it is this method of performance which leads to the interaction between presentation type and nameability, where the separate mechanisms are differentially affected by experimental stimuli. The lack of this interaction in the older group fits with the hypothesis that older adults are using the same or overlapping mechanisms to perform visual and spatial tasks. Specifically, visuo-spatial memory systems in older adults may have become dedifferentiated. The sequential presentation in Experiment 4 lent itself to the use of strategies that are available during simultaneous presentation, such as chunking, drawing on visual semantics, or verbal coding (Brown & Wesley, 2013; Parmentier et al. 2005; Parmentier & Andres, 2006). The randomised nature of the sequential presentation in Experiment 5, however, likely rendered such strategies ineffective, or too difficult to implement, resulting in the lack of nameability effect in the sequential task, as well as the weakened nameability benefit in the simultaneous task in older adults. Thus, Experiment 5 has shown that the nameability effect in the simultaneous task is not as robust in older adults as it is in younger adults.
It is also possible that, to a greater degree than in young adults, older adults’ performance on one administration of a visual working memory task can affect performance on subsequent iterations of task.

A recap of Chapter 3

The overall aim of these experiments was to assess the replicability and generalizability of the Brown et al. (2006) ‘Nameability Effect’ in young and older adults on differing versions of the VPT. It was expected that young (18-25) and older (60-75) adults would show a benefit from ETN patterns in the traditional form of the VPT using simultaneous presentation. It was also hypothesised that the older group may demonstrate a nameability effect in a sequentially presented version of the task where the pattern of presentation followed a set order. Results in the younger group have replicated Brown et al. (2006) by demonstrating a robust nameability effect in simultaneous versions of the VPT. This nameability effect is important as it demonstrates the ability to increase visual working memory capacity by drawing on apparently flexible, generalised resources, (possibly including activation of semantic visual information, Brown & Wesley, 2013). Notably, younger adults do not demonstrate a nameability effect in the sequential version of the task in either of the presentation methods used here. This is further evidence of the separability of visual and spatial mechanisms within the visuo-spatial sketchpad in young adults (Della Sala et al., 1999; Logie & Pearson, 1997). Brown and Wesley (2013) have shown the mechanism that leads to this effect cannot be attributed to pure articulatory rehearsal using the phonological loop; rather it appears to arise as a function of an executive strategy, as demonstrated by interference from a random spatial tapping task.
Individual differences in terms of self-reported strategies also appear to be a mediating factor, further illustrating the flexible and strategic application of executive resources. Note that semantic information could potentially also be drawn upon relatively automatically, suggesting a possible role for the episodic buffer in retaining ‘chunks’ of information. However those who perform best on a demanding visual working memory task tend to be those who report active use of different strategies, further evincing the role for executive resources (Brown & Wesley, 2013).

The present evidence shows that, under the right conditions; in this case a visual patterns task presented in a simultaneous format, older adults will demonstrate the same nameability effect as young adults. However, this nameability effect is only found when individuals also perform a sequential-ordered version of the task. When older participants perform sequential-randomised tasks as well as the simultaneous task there is no nameability benefit in either presentation type. Perhaps most important is the finding is that, in both experiments, there were presentation type x nameability interactions in young adults, but no such interactions in the older adults. This is consistent with the hypothesis put forward by Johnson et al. (2010) that older adults tend to use general resources to perform visual tasks. It also implies that prior knowledge of how to perform a memory task or how to encode the information presented can possibly affect performance on any subsequent administration of the same, or a similar task. This leads to the possibility that, whilst the VPT remains a measure of visual short-term memory, repeated exposure to the task may also lead to it becoming a measure of previous VPT task experience. Specifically, the presentation type x age group interaction in both experiments highlights a greater similarity between simultaneous and sequential scores in the older group compared to the young group. This increased generalizability between performance on two different versions of the task may be evidence for the age related dedifferentiation in visuospatial task abilities (Chen et al., 2002). The use of selective interference paradigms in simultaneous and sequential tasks would allow future exploration of the nature the individual differences that lead to a participant’s maximum task performance.
What then, are the cognitive functions that lead to these patterns of performance? It is suggested that older adults will employ a strategy to complete a given set of tasks. The choice of strategy will be affected by the nature of the first task presented, but once decided upon; older adults will be less likely to diverge from this strategy than younger adults. Participants in Experiment 4 were presented with two tasks that lent themselves to a strategy such as verbal encoding, or labelling (Brown et al., 2006; Lecerf & De Ribaupierre, 2005; Parmentier & Andres, 2006). Older adults may have found that the mechanisms used to perform in one presentation mode would have been beneficial in the other presentation mode. However, in Experiment 5 the increased complexity of the patterns created through randomised presentation of the sequential task would not have been amenable to the strategies that afford a benefit in the simultaneous condition. Participants who were presented with the simultaneous task first would have found that the method for performing that task did not translate to the sequential task. Conversely those who performed the sequential task first would have found difficulty in producing a labelling strategy that could compensate for the age-related decline in task performance. (Analysis of the administration order of tasks shows a marginal effect of ETN or HTN pattern set presented first in the older adults. However, due to counterbalanced nature of the experiment, the groups being compared each have an n = 6. Future research in this thesis will assess the effects of order of presentation). This explanation is theoretically supported by STAC (Park and Reuter-Lorenz, 2009), and the findings of Johnson et al. (2010). In both cases it is suggested that younger adults perform visual tasks using more specific, specialised resources than their older counterparts, and in the case of STAC, older adults will demonstrate the increased frontal activation seen as evidence of compensatory recruitment in order to aid task performance at a lower level of complexity than younger adults.

What is also possible within the results seen here is that there may be no qualitative differences between the mechanisms used by young and older adults in the sequential tasks. A non-spatial rehearsal strategy may be practised by both groups, but it may benefit younger adults more than it does older adults. In the sequential ordered tasks of Experiment 4, both age groups demonstrated higher overall scores than in the sequential randomised tasks of Experiment 5. It is possible that in the sequential task
of Experiment 4 both groups were using a non-spatial strategy, and benefitting from the ordered presentation. The younger adults may have been more efficient at alternative strategies such as path creation, or chunking (Non-spatial strategies suggested by Parmentier et al., 2005; Parmentier and Andres, 2006) than the older adults. The older adult nameability effect may have been the result of less efficient use these non-spatial methods and the amenability of the ETN pattern set to multimodal encoding may have led to the nameability benefit seen in older adults. In Experiment 5 the randomised nature of the sequential presentation may have negated any attempts at alternative strategies for either age-group. This is reflected by the poor performance seen in both young and older adults.

The interpretation of the results seen here has been framed as a change in the use of multiple-component model systems with age. However, the interpretation is also compatible with other models of short term memory. Notably the Unsworth & Engle (2006) system of primary memory (PM) and secondary memory (SM). Initially, at low levels of complexity, the VPT would measure only PM. Smaller patterns with fewer to-be-remembered squares could be held in the primary memory system. However, as patterns grow larger, and there are more squares to-be-remembered, the recruitment of SM would be required. The task would then start to measure the efficiency of an individual to manipulate information into a manageable form and link it with new information being presented (Unsworth & Engle, 2007b). It is possible that we are measuring a decline in PM in older adults, and a greater reliance on SM. Older adults may need to-be-remembered information to lend itself to combinations in order to reduce the load on PM, and the efficiency of SM. In turn younger adults may be able to call on SM, but not rely on it, due to intact PM systems. This could be analogous to suggesting a decline in the visual system of the Multiple Component Model with age, and a greater reliance on central executive functions (possibly in the form of directed attention to the episodic buffer) with age. This explanation, when framed in either model would be supported by one of the key tenets of STAC. Namely, that compensatory behaviour maintains, but never exceeds the original levels of cognitive performance (Park & Reuter-Lorenz, 2009). This possible explanation does not, however account for why we do not see a greater benefit from ETN pattern sets in
older adults if older adults are maintaining more semantic, rather than visual information. It may be that reliance on a non-short-term-memory specific system to carry out a short-term-memory task is an inefficient technique which reduces any possible benefits; however this is not known or testable at this stage of the thesis.

Based on the pattern of results seen in Experiments 4 and 5, two further lines of research are suggested. The first is assessing the effects of order of presentation on task performance. If the manner in which individuals approach working memory tasks is affected by the tasks they have previously undertaken, we would expect to see differences in overall scores, and phenomena such as the nameability effect. Darling et al. (2012) demonstrated a trend towards adaptation of cross-modal encoding within a working memory task when using a digit span task, presenting numbers in a novel spatial layout. As the layout became less novel, and allowed for spatial as well as verbal encoding, there was a trend towards improved performance. Furthermore, there is a trend in the data from Experiment 4 that suggests younger adults demonstrate higher scores when ETN patterns are presented first. In Experiment 5, where the sequential task did not lend itself to encoding, older adults show a trend towards displaying higher scores when HTN patterns are seen first. One interpretation for this is that those older adults who were presented with the ETN patterns first attempted to continue with a naming strategy, but this proved to be ineffective, thus lowering scores. However, the experiments presented here were designed in order to assess the nameability effect in simultaneous and sequential tasks. Due to the counterbalancing used in the study there are very small subgroups with which to measure order effects. Assessing these effects in an optimally designed study will afford a far more reliable measure of the possibility of general strategy use in older adults.

The second direction for future research should be based on the use of executive tasks within selective interference paradigms. Brown and Wesley (2013) have already demonstrated that executive random tapping task, relative to a repetitive tapping task, can remove the nameability effect. Additionally, Rudkin et al. (2007) have demonstrated increased recruitment of executive resources within spatio-sequential tasks. These effects should be further explored in both young and older adults in both simultaneous and sequential versions of the VPT. This is particularly the case as the
ability specifically to combine short- and long-term memory resources could be specifically affected by ageing, and this would explain the age-related reduction of the nameability effect observed presently.

There are differential patterns of performance in simultaneous and sequential tasks between young and older adults on differing versions of the visual patterns task. However, it is not possible to say that these differences are related, purely to the availability of verbal encoding through the use of the Brown et al. (2006) ETN/HTN patterns. The manner of presentation and the demands of other tasks within an experiment affect the outcome. In conclusion the results here are consistent with the findings of Johnson et al. (2010), Chen et al. (2002), and the concept of STAC (Park and Reuter-Lorenz, 2009). Specifically, with older age, performance of a visual short-term memory task appears to increasingly rely upon generalised resources. Patterns of performance in older adults are more consistent across all tasks within an experiment, whereas younger adults show differential patterns of performance across visual and spatial tasks. These results are in accordance with the Multiple Component Model of working memory (Baddeley & Hitch, 1974; Baddeley, 1983; 1986; 2000; Logie, 1995; Logie, 2011), however they are also compatible with the Unsworth and Engle (2006; 2007a; 2007b) PM/SM distinction.
The data gathered in Chapter 3 led to the formation of two further questions concerning the nature of visual pattern task (VPT) performance in healthy older adults. These first concerned the nature of presentation order effects on performance in the VPT. The second concerned the need to assess the effects of executive interference tasks on performance. Experiments 6 and 7 were designed to assess presentation order effects in both young and older adults. This was conducted through repeated performance of the VPT with four differing pattern sets.

Experiment 8 focused on the possible differences in interference effects from verbal and executive interference tasks on VPT performance in young and older adults. All participants were measured to find their visual span level. Participants then performed verbal and executive interference tasks during maintenance of visual pattern information at, and at one level below participants’ maximum span levels.

**Experiment 6**

**Introduction**

The possibility that overall VPT performance is affected by the order in which experimental conditions are administered was assessed in two experiments, each containing four experimental conditions. The first of these conditions involved undertaking the VPT with presentation of either the easy-to-name (ETN) or hard-to-name (HTN) pattern sets used in Chapter 3 (developed by Brown et al., 2006). The second and third experimental conditions involved the presentation of the two randomly generated ‘neutral’ pattern sets (see pilot study below for a full description of their development). The fourth condition involved the presentation of the remaining HTN or ETN pattern set. Experiment 6 assessed performance on simultaneously presented information, whilst Experiment 7 used sequentially presented information.
The dependent measure in both experiments was an individual’s maximum capacity (span).

Data from Experiments 4 and 5 suggested that the presence of the Brown et al. (2006) nameability effect in older adults may be dependent on the nature of other visuospatial tasks conducted within the same experiment. Participants in Experiment 5 were required to carry out both the simultaneous version of the VPT and the sequential version with randomised path presentation. This led to a loss of the positive effect of the ETN pattern set seen in Experiment 4 for older adults in both the simultaneous and sequential tasks. Parmentier et al. (2005) suggested that non-structured sequential presentation pathways, such as those seen in Experiment 5, could be detrimental to strategies such as verbal recoding or path creation which might be used to enhance recall of presented sequences. It is possible that when faced with such an occurrence in the presentation of sequential-random pattern sets, older adults subsequently struggled to maintain a system of verbal or semantic encoding that may have previously been leading to the nameability benefit with ETN patterns.

The general hypothesis for this work has been that older adults may be performing visuospatial tasks using generalised task resources, rather than the task specific resources that are apparent in children and younger adults (Della Sala et al., 1999; Logie & Pearson, 1997). The results of Experiments 1, 2 and 3 within this thesis have shown that older adults experience differential interference from articulatory suppression in visual tasks compared to younger adults. These patterns of interference suggest that older adults employ both verbal and visual resources to attempt completion of visual memory tasks. For older adults, it is possible that performing an inefficient non-visual task strategy in one experimental condition can affect performance on subsequent tasks. A similar situation could arise with the presentation either ETN or HTN patterns in the first condition of an experiment. The differing properties of the pattern sets could direct an individual’s performance and affect the manner in which they attempted to perform subsequent versions of the VPT. Therefore it was unclear which effects on task performance in Experiments 4 and 5 were derived from the methods of pattern presentation, and which were derived from the order of task presentation. Experiments 6 and 7 were designed to isolate performance in
simultaneous and sequential-ordered versions of the VPT in order to assess the possibility that participants performance on the tasks could be directed by the level of available verbal coding in the first pattern set presented to them.

The experimental design for Experiments 6 and 7 allowed for three research questions relating to presentation order effects to be assessed. The first is whether the presentation of ETN or HTN patterns first in an experiment will affect performance on two sets of ‘neutral’ patterns. The second is whether the nameability effect is robust against any effects of presentation order. The final question relates to the nature of those who demonstrate nameability. Are those who show the nameability effect those who have higher, or lower overall VPT performance? Justification and discussion of these questions is provided below. Experiment 6 will focus on simultaneous presentation of visual patterns, Experiment 7 will use the sequential-ordered pathway presentation method used in Experiment 4.

**Does pattern presentation order affect performance on neutral pattern sets?**

It is possible that, when being presented with individual conditions in an experiment, older adults experience interference effects from the demands of previous conditions (Anderson, Reinholz, Kuhl, & Mayr, 2011). Experiments 4 and 5 both demonstrated a lack of presentation type x nameability interaction in older adults. This could represent a number of behavioural phenomena. It may be that older adults do not employ separable mechanisms for the maintenance of simultaneous, or spatio-sequentially presented information. It may be that the main effect of age on task performance has led to a reduction in the abilities or memory stores that allowed for specialised task performance when they were younger (Johnson et. al., 2010; Park & Reuter-Lorenz, 2009). Finally, it is possible that older adults are simply performing a memory task using two different strategies, but there is no interaction between presentation type and nameability as the performance using separable strategies is comparable in terms of overall outcome.
The first question in this study assessed the possibility that older adults may experience a form of proactive interference when performing the VPT after presentation of either ETN, or HTN patterns. It is possible that performance on subsequent versions of the VPT is guided by the characteristics and outcomes of the first version of the VPT presented. The literature on directed forgetting paradigms (which typically involve a presentation phase followed by a recall phase, with instructions that certain presented information is irrelevant to the task), suggest that older adults are less efficient at forgetting previously presented irrelevant information when compared with younger adults (Sahakyan, Delaney, & Goodmon, 2008; Zacks, Radvansky, & Hasher, 1996).

Zacks et al. (1996) found that older adults produced more to-be-forgotten items, compared to younger adults in an immediate recall test, and took longer, compared to their own baseline performance to reject to-be-forgotten items in a recognition test. Sahakyan et al. (2008) found that age-related deficits in directed forgetting were likely due to older adults being less likely to actively implement a strategy to forget compared to younger adults. Older adults were capable of achieving directed forgetting but had to be explicitly guided into a strategy which would be beneficial to them. Anderson et al. (2011) used a think/no-think paradigm to assess directed forgetting in young and older adults. Older adults showed consistently better recall than younger adults for items that were intended to be forgotten, compared to baseline items in an independent probe think/no-think task. This was taken as evidence that the ability to engage inhibition in order to suppress retrieval of information declines with age. The three papers presented here are consistent with the inhibition deficiency hypothesis of ageing discussed in the Chapter 1 of this thesis (Hasher & Zacks, 1988). This suggests that older adults struggle to actively inhibit irrelevant task information, thus causing performance issues in tasks involving comprehension, selective remembering and discussion of events. Zellner & Bauml (2006) have suggested that this inhibition deficit may be specific to a lack of inhibition at encoding of information, rather than at retrieval. This is commensurate with the concept of crossover condition effects from previously presented information affecting the method of encoding or maintenance suggested here. Namely, that previously encountered versions of the VPT affect the manner in which older participants attempt to perform any subsequent version of the VPT.
There is also evidence from the literature to suggest that ability to suppress previously presented information is related to working memory performance. Rosen and Engle (1997) demonstrated that there was a relationship between working memory capacity and the ability to suppress intrusive thoughts. In the first of a series of two experiments participants with high working memory spans displayed significantly fewer intrusions from a previously learned list on recall of subsequent information than low span participants. In the second experiment high span participants were slower (compared to controls) at retrieving items from an original list after suppressing that information during second and third lists. This effect was not seen in the low span participants. Rosen and Engle suggested that this showed a possible link between intrusions, working memory capacity, and frontal lobe function. This suggested that low span individuals displayed a deficit in the control of attention compared to their high span counterparts. It may be that this deficit in attention control in low span participants is similar to the reduced ability to inhibit irrelevant information at encoding seen in older adults (Zacks et al., 1996).

It is possible that it is not just the order of separate tasks, but the structure of individual tasks that leads to interference effects in older adults’ VPT performance. Lustig, May, and Hasher (2001) used three versions of the reading span task to demonstrate that proactive interference from previous task stimuli in a traditional ascending set size span measure had a greater effect on older adults than it did on young. Participants were presented with the reading span task using either traditional ascending (increasing set size), descending (decreasing set size) presentation methods, or descending presentation with breaks between set sizes. It was hypothesised that presenting the larger, more difficult to remember word sets at an earlier stage would reduce the proactive interference from earlier small set sizes and lead to a benefit for older adults compared to performance in the traditional ascending condition. Older, but not younger adults improved their span scores in the descending condition. Younger adults’ scores were improved compared to the ascending and descending tasks in the descending with breaks task. It was suggested that it is likely that both young and older adults suffer from proactive interference, but this effect is felt more strongly in older adults.
It has been seen that older adults do demonstrate a reduced ability to forget previously presented information compared to that seen in young adults. This suggests that a proactive interference ‘condition crossover effect’ is likely to be seen in this experiment. The working memory span tasks used Lustig et al. (2001) and the directed forgetting paradigms used by Anderson et al. (2011), Sahakyan et al. (2008) and Zacks et al. (1996) suggest there is an effect of knowledge from previous tasks on completion of short-term memory tasks. It is possible that this increased proactive interference affects older adults on the ETN and HTN versions of the VPT, by directing the mechanisms which are recruited for task performance.

The proactive interference considered so far revolves around the possibility that to-be-remembered information in one condition can affect to-be-remembered information in another condition. It has also been shown that prior knowledge of how to perform a task, or an increased familiarity with the information presented can be of benefit to both young and older adults. The visual bootstrapping effect (Darling et al., 2010; 2012) has shown that long term knowledge can affect digit recall when numbers are presented in a keypad layout. A familiar layout that matches a traditional telephone keypad improves performance, whilst unfamiliar layouts do not have any benefit over more common methods of presentation, such as presenting digits in a line. The SNARC effect (Dehaene et al., 2005) also suggests that a familiar schema of numerical layouts has an effect on recall. This is not consistent with these verbal tasks being pure measures of short term memory storage, and indicates a role for a multimodal mechanism such as the episodic buffer (Darling & Havelka, 2010). Corresponding evidence from within the visual domain has been shown by Brown et al. (2006), Brown and Wesley (2013), and from data within this thesis. Both young and older adults can demonstrate higher VPT spans when performing the VPT using ETN pattern sets compared to HTN pattern sets. Participants’ performance on a visual memory task is improved when presented with patterns which can be more easily ascribed verbal labels. If the increased proactive interference seen in older adults also relates to the manner in which participants approach a task, as well as to the information recalled, then it is likely that there will be an effect on older adults’ performance on ‘neutral’ pattern sets that is dependent on whether they were presented with ETN or HTN patterns first.
Does the nameability effect remain regardless of presentation order?

Brown et al. (2006), Brown and Wesley (2013), and data from this thesis have demonstrated a positive effect of ETN patterns compared to HTN patterns in the VPT. If the positive effect on performance in the ETN pattern set seen in Experiments 4 and 5 is due to an inherent quality of the pattern set, rather than a comparative quality of the ETN set against the HTN set then it would be expected that the nameability effect would still be seen when ETN/HTN patterns are presented with a buffer of two neutral pattern sets.

The studies using the ETN/HTN pattern sets within this thesis have all been of a repeated measures design where participants were being presented with both the ETN and the HTN pattern set. As such, it may have been the dichotomy of the two pattern sets that was creating the nameability effect. The qualities that lead to each pattern being ascribed into either set may have also contributed to an inherent difficulty in recollection for the HTN set. In Experiment 5 it was apparent in the older age group, that when both pattern sets were presented in a manner designed to remove any artefacts of nameability (sequential-random paths) that the nameability effect was lost, not just in the sequential task, but in the simultaneous task too.

The original Brown et al. (2006) study used a between-subjects design to identify the nameability effect. This demonstrates that there is not just a comparative benefit of ETN patterns against HTN patterns leading to a higher group aggregate performance in the ETN set. However, it does not provide any information regarding interference effects from condition-to-condition. It is possible that the introduction of the two neutral pattern sets to assess order effects will also provide information on whether the magnitude of the nameability effect is reduced when there is no direct comparison between ETN and HTN patterns between conditions.
Are there different levels of performance between ‘Namers’ and ‘non-Namers’?

One question, relating to any theory of compensatory recruitment, or strategy use in memory tasks is whether those who are demonstrating the more generalised recruitment are the individuals that are performing well, or are the individuals struggling to maintain performance.

Typical structures associated with increased activation in old age include the Dorsolateral Pre-Frontal Cortex (DLPFC) (Reuter-Lorenz, Marshuetz, Jonides, Smith, Hartley & Koepp, 2001). Cappell, Gmeindl, and Reuter-Lorenz, (2010) found age related over and under activation of the DLPFC in older adults. Older adults showed over recruitment of the DLPFC during verbal memory task performance at low loads, and a relative under recruitment of the DLPFC at high memory loads. This under-activation at higher loads was associated with a drop in task performance in older adults. Reuter-Lorenz et al. (2001) and Rypma, Prabhakaran, Desmond, and Gabrielli (2001) found over recruitment of frontal executive resources such as the DLPFC in older adults during tasks that are typically parietal, maintenance only tasks for younger adults. This suggests that older adults demonstrate increased frontal recruitment to maintain, rather than increase overall task performance.

Whilst increased recruitment may be a method of maintenance of task performance in older adults, it also appears to be a method of improving task performance in younger adults. Studies of working memory and short term memory capacity show that there is a greater relationship between performance in simple, and complex memory tasks in higher ability participants compared to lower ability participants (Unsworth & Engle, 2006). This suggests that the mechanisms used to perform complex span tasks may be employed to improve performance in simple span tasks. Furthermore, those with higher capacities in single task conditions show a greater dual-task decrement, suggesting that a greater level of domain general recruitment on top of domain specific recruitment is used at higher levels of single task performance (Rosen & Engle, 1997).

The Compensation-Related Utilisation of Neural Circuits Hypothesis (CRUNCH; Reuter-Lorenz & Cappell, 2008) and Scaffolding Theory (Park & Reuter-Lorenz,
suggest that the compensatory recruitment seen in older adults is akin to the methods used to increase task performance in younger adults. It is posited that cognitive scaffolding in older adults cannot replace the original mechanisms of task performance (Park & Reuter-Lorenz, 2009). As such it is expected that the demonstration of a nameability effect will be an indicator of higher overall task performance in younger adults (In accordance with Rosen & Engle, 1997; See also Brown & Wesley, 2013). It is not expected that those who demonstrate nameability in the older group will demonstrate an increase in overall task performance.

**Development of neutral pattern sets**

The design of Experiments 6 & 7 necessitated the development of two ‘neutral’ pattern sets that fell into the middle of the ETN/HTN spectrum. The aim of this pilot study was to produce two pattern sets for which participants would demonstrate mean scores that were between the mean scores of the ETN and HTN pattern sets in the simultaneous condition of Experiment 4. As the Brown et al. (2006) ETN/HTN pattern sets were derived using simultaneous presentation with younger adults only, it was decided that this method would be used for the presentation of new pattern sets.

It was decided that defining patterns as ‘neutral’ patterns through performance scores was a more objective measure than questioning participants on the abstract notion of a ‘neutral’ nameability level. It was also decided, that as participants were never informed of the nameability of either ETN or HTN shapes prior to any study, any neutral sets should not be chosen on that basis. As such, the qualities that have led to the ‘neutral’ nameability pattern set scores are similar to those that affected pattern scores in either ETN or HTN pattern sets.

A random number generator was used to generate random sequences of numbers. These numbers translated to squares on presentation grids. These patterns were then presented to participants using the same procedure for simultaneous task performance as used in Experiment’s 4 & 5. Patterns were presented to groups of twelve participants and particularly difficult/ or particularly well recalled patterns were removed and replaced with new randomly generated patterns until the two neutral
patterns produced the requisite mean scores. The mean scores in the simultaneous presentation condition for young adults in Experiment 4 were 10.03 (SD = 1.89) for ETN patterns and 9.01 (SD = 2.03) for HTN patterns. The mean scores for the final two neutral pattern sets with 12 young adults (Mean age = 20.25, SD = 2.38) were 9.91 (SD = 1.37) and 9.25 (SD = 1.75). There was no significant difference between performance on the two neutral pattern sets, t (11) = 1.59, p < .14. These would be used as the neutral pattern sets for Experiments 6 & 7.

**Methods**

**Participants**

Two groups of participants took part in the study. Twenty-four younger (16 females, 8 males) adults aged 18-25 (Mean = 20.63, SD = 2.28) and 24 healthy older adults (18 females, 6 males) aged 60-75 (Mean = 67.25, SD = 3.81, Mean MMSE = 29.42, SD = .72). The 24 younger participants had a mean education level of 2.58 (SD = .78). The 24 older participants had a mean education level of 2.79 (SD = .51). There was no significant difference in education level between young and older adults, t (46) = 1.1, p = .28. Younger adults were recruited through the University of Edinburgh part-time recruitment website, or were taking part for course credit. Older adults were recruited from the University of Edinburgh volunteer panel. All participants were paid £5 for their time (other than those taking part for course credit), and all reported normal, or corrected-to-normal vision. No participants in Experiment 6 had also taken part in Experiments 4 or 5.

**Design**

The study was a between-groups 2 (age group) x 2 (presentation order: ETN/HTN first) design. Participants completed four experimental conditions. Condition 1: either ETN or HTN patterns, Conditions 2 & 3: two neutral pattern sets, and Condition 4: the remaining HTN or ETN pattern set. Participants’ maximum span level was used as a performance measure.

**Procedure**
Participants were tested individually in a quiet testing room. Older adults initially undertook the MMSE (Folstein et al., 1975). All participants provided gender, age and education level. All participants undertook a brief practice task. This involved the presentation of 3 pattern sets for recall at the lowest level of complexity (Four squares to remember. These patterns were not used in the experimental study.) Satisfactory performance in the practice task was deemed to be 2 out of 3 patterns correctly recalled (this represented the level of performance needed to pass an experimental level).

Participants began the experimental session by being presented with either the ETN or HTN pattern set. The initial presentation level comprised 3 sets of patterns with 8 squares overall and 4 black squares to recall. Completely correct recall of at least two patterns ensured the experiment would move on to a grid with 10 squares comprising 5 black squares to recall. This process of increasing set sizes continued until participants could no longer recall 2 out of 3 patterns correctly. The largest possible grid size comprised 30 squares with 15 black squares to recall. No participants passed this level. Participants span level was deemed to be the mean number of squares in each of the last three correctly recalled patterns (2 correct patterns with 10 squares and 1 with 11 squares would result in a span of 10.33). After reaching span level on the first pattern set, participants would repeat the process with two neutral pattern sets, and then the remaining ETN/HTN pattern set.

The study started with an information screen which prompted participants to tap the screen when they were ready to continue. The task began with a fixation cross presented for 500ms. To-be-remembered information was presented for 3000ms. This was followed by a 10000ms blank blue screen. A blank version of the original grid was then displayed. This remained on display until the participant had entered the requisite number of squares. Each blank square could only be selected once. Participants were unable to delete choices. This decision was taken to prevent participants changing the pattern until they recognised it from presentation.

**Results**

**Memory tasks**

The first stage of assessment was to see if there were significant differences in the span scores reached on the two ‘neutral’ pattern sets. Repeated measures t-tests showed that
there was no difference in mean span level between the first and second neutral pattern set (Neutral Set 1 Mean = 8.30, SD = 1.89, Neutral Set 2 Mean = 8.60, SD = 2.23, t (47) = -1.21, p = .23. As such, participants’ scores on the two neutral pattern sets were combined to form a single outcome measure ‘neutral pattern average’. This was used as the dependent variable in subsequent

The effect of pattern set presentation order on the neutral pattern average was assessed by a two-way between subjects ANOVA (age group x pattern set presentation order) with neutral pattern average as the dependent variable. There was a main effect of age-group on the neutral pattern average, F (1,44) = 21.94, p < .001, η²p = .33, younger adults demonstrated higher mean spans than older adults. There was no main effect of presentation order, F (1,44) = 1.98, p = .17, η²p = .04. There was a presentation order x age group interaction, F (1,44) = 4.013, p < .05, η²p = .08. Bonferroni adjusted t-tests showed that older adults demonstrated higher neutral pattern scores after presentation of ETN patterns first (M = 8.17, SD = .86) compared to the HTN pattern first condition (M = 6.67, SD = 1.49), t (22) = 3.03, p < .001. This was not present in younger adults (ETN First mean = 9.35, SD = 2.13), HTN first mean = 9.61, SD = 1.34), t (18.48) = -.362, p = .99. In the ETN first condition there was no significant difference in the neutral pattern average variable for the younger group compared to the older group, t (22) = -1.78, p = .09. In the HTN first condition younger adults showed significantly higher scores compared to older adults, t (22), -5.10, p < .001.
Fig 4.1: Mean scores on neutral pattern scores for both age groups with high and low verbal coding patterns presented first in a simultaneous presentation task. (Error bars represent Standard Error of the Mean).

The second research question used a mixed ANOVA with two between subjects variables (age-group and ETN/HTN first presentation order) and one within subjects variable (nameability effect). The aim was to identify if the nameability effect (higher performance on ETN patterns) interacted with either age group or pattern presentation order. There was a main effect of nameability, \( F(1,44) = 8.44, p < .01, \eta^2_p = .17 \), with higher scores in the ETN condition than in the HTN condition. There was no nameability x age group interaction, \( F(1,44) = 1.082, p = .30, \eta^2_p = .02 \), or nameability x presentation order interaction, \( F(1,44) = 3.68, p = .06, \eta^2_p = .07 \). There was no three-way interaction between nameability, age group and presentation order, \( F(1,44) = .78, p = .38, \eta^2_p = .02 \). The nameability effect seen in previous experiments appears to be robust to changes in presentation order of ETN and HTN pattern sets, as well as the insertion of two neutral pattern sets between presentations. (See fig 4.2)
In order to assess whether the presence of a nameability effect (defined as higher scores in the ETN pattern set compared to the HTN pattern set) was related to higher levels of overall memory performance, participants were divided into two groups based on whether they showed a nameability effect. This created a ‘Namer’ and ‘Non-Namer’ group. A two-way, between groups ANOVA (age group and Namer/non-Namer as between group independent variables) on performance in the neutral pattern average dependent variable was conducted. (See table 4.1 for Namer/age group mean scores on neutral pattern average). There was no significant effect on neutral pattern average of being a Namer/Non-Namer, $F (1,44) = .71, p < .40, \eta^2_p = .02$. There was a significant effect of age group, $F (1,44) = 18.92, p < .001, \eta^2_p = .13$, with younger adults demonstrating higher mean neutral set scores than older adults. Finally there was a Namer x age group interaction, $F (1,44) = 6.78, p < .01, \eta^2_p = .133$. Bonferroni adjusted t-tests showed that younger adults who were Namers had significantly higher scores on the neutral average condition than younger adults who were Non-Namers, $t (22) = -2.26, p < .02$. This was not present in the older adult Namers compared to older Non-Namers, $t (22) = 1.36, p = .19$. Young Namers had significantly higher scores than older Namers, $t (25) = -4.99 = p < .001$. Young Non-Namers did not significantly differ from older Non-Namers, $t (19) = -1.26, p = .446$. 

**Fig 4.2:** Mean scores on ETN/HTN pattern sets for both age groups with ETN or HTN patterns presented first. (Error bars represent Standard Error of the Mean).
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<tr>
<th></th>
<th>Young Namer</th>
<th>Young Non-Namer</th>
<th>Older Namer</th>
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<tr>
<td><strong>N</strong></td>
<td>14</td>
<td>10</td>
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<td>11</td>
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<tr>
<td><strong>Neutral Pattern Span</strong></td>
<td>10.10</td>
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<td><strong>SD</strong></td>
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<td>1.52</td>
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**Table 4.1:** Mean scores on neutral pattern scores for both age groups split into sub-groups based on the presence of nameability effect in ETN/HTN pattern sets.

**Discussion**

Participants were presented with four versions of the simultaneously presented VPT. In the first instance participants were presented with either ETN or HTN patterns, this was followed by presentation of two neutral pattern sets, and then the remaining ETN/HTN pattern set. Older adults showed significantly improved mean scores on the neutral pattern sets when presented with ETN rather than HTN shapes in the first condition. There was no effect of pattern presentation order on younger adults. In both young and older adults there remained a main effect of nameability between ETN and HTN pattern sets, with higher mean scores in the ETN pattern set compared to the HTN pattern set, regardless of presentation order. When participants were split into two groups based on the presence of a nameability effect, it was found that younger adults who demonstrate a nameability effect show significantly improved performance on neutral pattern sets compared to those who do not display a nameability effect. This difference was not seen for older adults.

The presence of age group effects in the first and third research questions presented here do suggest a qualitatively different approach to visual memory task performance between young and older adults. One suggestion for the positive effect of ETN pattern first presentation on older adults is that the higher mean performance for the ETN
patterns translates into a greater number of pattern presentations, and therefore represents a practice effect benefit on the neutral pattern set performance. This is unlikely as it should correspond with an improved performance in the HTN pattern set and a loss of the overall nameability effect, which is not seen in this dataset. The overall nameability effect with no age group interaction suggests that there is a difference between ETN/HTN patterns that leads to a difference in task performance that is over and above the mechanisms underlying the age-related changes in performance in other aspects of this study.

As was expected, being a participant who demonstrated a nameability benefit led to higher scores on the neutral pattern sets in the younger adults, but not the older adults. The benefit of being a Namer for the younger adults provides experimental support for Brown and Wesley (2013), who found that participants who reported a ‘combining’ task strategy (combining of visual and verbal strategies to perform the VPT) displayed significantly higher scores than ‘non-combiners’. This study reiterates that point, but with participants divided into combiners/non-combiners through behavioural rather than qualitative assessment. The lack of a nameability benefit for older adults corresponds with the suggestions of Scaffolding Theory, which state that compensatory recruitment can maintain, but never outperform the performance of the original mechanism (Park & Reuter-Lorenz, 2009).

How then, can this interpretation be reconciled with the improved performance seen in younger adults who showed a nameability effect? It may be that there is a qualitative difference behind the recruitment of additional non-domain general mechanisms for task performance. Additional recruitment may be used as a method to improve task performance in younger adults, but may not be a conscious choice in older adults. Hartley et al. (2001) demonstrated a relation between visual task performance and object naming ability in older adults. It was suggested that older adults may be unable to inhibit recruitment of verbal resources when performing any given task. Hartley et al. posited that compensatory recruitment was a passive, reactive occurrence, rather than active, strategic response for older adults. It may be that this is the case for older adults in this experiment, and that younger adults are able to choose an appropriate method for task performance. This corresponds with data from Chapter 2 of this thesis,
which highlighted that older adults were employing verbal mechanisms during visual task performance, whether these were of benefit to performance or not.

**Experiment 7**

In Chapter 3, Experiments 4 and 5 used simultaneous, sequential-ordered, and sequential-randomised presentation of the VPT with young and older adults. Therefore any effects of ETN/HTN pattern presentation may have been affected by the presentation methods used. Experiments 6 and 7 were designed to assess a number of research questions concerning ETN/HTN pattern sets using simultaneous and sequential versions of the VPT in isolation. Experiment 7 mirrors the design of Experiment 6, but with the use of the sequential version of the VPT. The sequential-randomised version of the task used in Experiment 5 appeared to remove any benefit of nameability within the pattern sets for both young and older adults. As this series of experiments was concerned with the possibility that verbal or semantic coding strategies were causes of proactive task interference in older adults the decision was taken to use the sequential-ordered presentation version of the VPT used in Experiment 4.

The same research questions posed in Experiment 6 were assessed in Experiment 7. It was hypothesised that, as with Experiment 6, the first pattern set presented would have an effect on performance in the neutral pattern sets for older adults. However, the hypotheses regarding the overall nameability effect differed due to results from Chapter 3 in this thesis. Younger adults did not demonstrate a nameability effect in either of the experiments with sequential presentation within Chapter 3 and as such it was not expected that one would be present in this study. However, older adults did demonstrate a nameability effect in the sequential-ordered task in experiment 4, and it was hypothesised that this would be present again. As with Experiment 6, it was expected that demonstrating a nameability effect would be an indicator of higher overall performance for the younger adults.
Methods

Participants

As with Experiment 6, two groups of participants took part in the study. The 24 younger participants (18 females, 6 males) had a mean age of 19.00 ($SD = 1.77$) and a mean education level of 2.38 ($SD = .65$). The 24 older participants (14 females, 10 males) had a mean age of 68.50 ($SD = 3.89$), a mean education level of 2.71 ($SD = .69$) and a mean MMSE score of 29.13 ($SD = .92$). There was no significant difference in education level between young and older adults, $t(46) = 1.73$, $p = .28$. All participants were recruited using the same methods as experiment 6 and again, all reported normal or corrected-to-normal vision. No participant in Experiment 7 had taken part in Experiments 4, 5 or 6.

Materials and design

The materials and design of the study were the same as those used in Experiment 6.

Procedure

The procedure for Experiment 7 broadly followed that of Experiment 6, the difference being in the manner of presentation of to-be-remembered information. Individual black squares within a pattern were presented one at a time in a sequential manner, rather than all at once as would be seen in a simultaneous presentation. After the presentation of a 500ms fixation cross, each to-be-remembered black square would be displayed for 1000ms. Squares were always presented in a left-to-right, top-to-bottom format, similar to the scanning process for reading text. After the requisite number of squares was displayed, a blank blue screen was displayed for 10000ms. This was followed by a blank version of the presentation grid. Participants were now required to recall the location of all black squares, in the correct serial order. As with Experiment 6, span level was deemed to be reached when participants could no longer completely correctly recall 2 out of 3 patterns at any one level of difficulty. This method of sequential pattern presentation was the same as the one employed in Experiment 4 of this thesis.
Results

Memory tasks

The same analyses conducted on the data from the simultaneous presentation experiment were used on the data from the sequential presentation experiment. As with Experiment 6 there was no difference in scores on the first or second neutral pattern set (Neutral Set 1 = 6.33, SD = 1.32; Neutral Set 2 = 6.57, SD = 1.62; \( t \) (47) = -1.37, \( p = .18 \)), as such these were amalgamated to form an outcome variable named as ‘neutral pattern set’ average.

The effect of ETN/HTN presentation order on the neutral pattern average was analysed using a two-way, between groups ANOVA (age group and pattern set presentation order as between groups independent variables) with neutral pattern set average as a dependent variable. There was a main effect of age-group on neutral pattern set score, \( F \) (1,44) = 33.60, \( p < .001 \), \( \eta^2_p = .43 \). Younger adults demonstrated higher scores than older adults. There was no main effect of presentation order, \( F \) (1,44) = .168, \( p = .20 \), \( \eta^2_p = .04 \). There was no presentation order x age group interaction, \( F \) (1,44) = .75, \( p = .39 \), \( \eta^2_p = .02 \).

Fig 4.3: Mean scores on neutral pattern scores for both age groups with high and low verbal coding patterns presented first in a sequential-ordered presentation task. (Error bars represent Standard Error of the Mean).

**Presentation Order Effects on Neutral Scores with Sequential-Ordered Presentation**

![Graph showing presentation order effects on neutral scores with sequential-ordered presentation.](image)
The effect of presentation order on the nameability effect was assessed through a mixed ANOVA with two between-groups independent variables (age-group and presentation order) and one within-groups dependent variable (nameability). There was no main effect of nameability, $F(1,44) = 2.15, p = .15, \eta^2_p = .05$. There was no nameability x age group interaction, $F(1,44) = 21, p = .65, \eta^2_p = .001$, or nameability x presentation order interaction, $F(1,44) = 297, p = .59, \eta^2_p = .001$. There was no three-way interaction between nameability, age group and presentation order, $F(1,44) = .01, p = .93, \eta^2_p = .001$). The nameability effect seen in the simultaneous task is not present in the sequential task. (See Fig 4.4)

**Fig 4.4:** Mean scores on ETN/HTN pattern sets for both age groups with ETN or HTN patterns presented first. (Error bars represent Standard Error of the Mean).

**Presentation order and the 'nameability' effect with Sequential-Ordered Presentation**

Performance in the neutral pattern sets based on the presence of a nameability effect was assessed by a two-way, between groups ANOVA (age group and Namer/non-Namers) on performance in the neutral average variable.). There was no significant effect of being a Namer/non-Namer, $F(1,44) = .44, p = .51, \eta^2_p = .01$ on neutral scores. There was a significant effect of age group, $F(1,44) = 36.83, p < .001, \eta^2_p = .46$ with younger adults demonstrating higher mean neutral set scores than older adults. There was a Namer x age group interaction, $F(1,44) = 4.06, p < .05, \eta^2_p = .08$, but Bonferroni adjusted t-tests showed no significant differences between Namers/non-Namers in
either age-group, \( t(22) = -0.92, p = .37 \). However there was a marginal trend towards non-Namers having higher scores than Namers in the younger group, \( t(16.98) = 1.97, p = .05 \), (alpha level following Bonferroni adjustments was \( p < .025 \)) this was not seen in the older group \( t(20.54) = -0.92, p = .367 \). (See table 4.2 for mean scores and group numbers). In both the Namer, and Non-Namer conditions, younger adults demonstrated higher scores than older adults (Namer condition: \( t(24) = -2.47, p < .04 \). Non-Namer condition: \( t(20) = -8.31, p < .001 \).)

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**Table 4.2**: Mean scores on neutral pattern scores for both age groups split into sub-groups based on the presence of nameability effect in ETN/HTN sequential-ordered pattern sets.

**Discussion**

As with Experiment 6 participants were presented with four versions of the VPT. However, in this experiment patterns were presented in the sequential-ordered manner previously used in Experiment 4. Unlike Experiment 6, neither age group demonstrated any order effects of either ETN/HTN patterns being presented first. The sequential nature of the presentation appears to have removed the condition crossover benefit for older adults of the ETN first presentation condition. In line with this, there was also no nameability effect for either age group regardless of presentation order. Finally, the benefit to neutral pattern scores for Namers in the young group was not seen in this experiment.

There was an unexpected failure to replicate the nameability effect seen in Experiment 4 in older adults with sequential-ordered presentation. There were two differences between the experiences of participants in Experiment 7 and Experiment 4 which may have led to the loss of this effect. In Experiment 4, participants undertook 4
experimental conditions that always involved presentation of either the ETN or HTN pattern sets. In Experiment 7 the introduction of two neutral sets may have led to a reduction in the apparent differences between ETN/HTN patterns for participants and thus affected any strategic method of task completion. It is unlikely though, that this is the case. If the presentation of neutral pattern sets were the cause of the loss of the sequential nameability effect then it may be reasonable to expect that this would have been the case in the simultaneous VPT too. However, in Experiment 6 the nameability effect remained for both age groups.

The second difference between the experiments was the absence of a simultaneously presented condition for participants in Experiment 7. Experiment 4 featured both simultaneous and sequential presentation. As such participants would, at some point experience the ETN patterns with simultaneous presentation. Experiment 6 has shown that this pattern/presentation type combination can benefit performance across task conditions for older adults, therefore this may have been the case in Experiment 4. In conditions where participants were presented with the simultaneous ETN condition prior to the sequential ETN condition, there may have been a crossover benefit which led to an overall nameability effect. Presentation of simultaneous ETN would have only occurred prior to presentation of sequential ETN in 50% of conditions, and simultaneous ETN before either sequential pattern would have only occurred for 33% of conditions. However, this does not mean that the performance of participants who were in those counterbalance conditions could not affect the group mean.

The interaction between demonstrating a nameability effect and neutral pattern score in the young adults was in an opposite direction to the one seen in Experiment 6. Bonferroni adjusted t-tests suggested a marginal, but non-significant trend towards a nameability effect being a marker of poorer overall task performance in younger adults. This suggests that a system of semantic or verbal recoding is not beneficial to performance in this spatio-sequential task. The sequential presentation of ETN/HTN patterns appears to ameliorate the qualities which allow for the simultaneous ETN/HTN patterns to be beneficially encoded or maintained through mechanisms other than purely visual stores. From the data presented here, it appears that it is the
nature of simultaneous presentation which leads to the nameability effect in young and older adults, as well as condition crossover effects in older adults.
A Recap of Experiments 6 & 7

There are a number of questions answered, and a number of questions raised by these experiments. In the first instance, it is apparent that for older adults, the similarities between performance in simultaneous and sequential versions of the visual patterns task are removed when the two methods of task presentation are not present in the same experiment. Older adults demonstrated matching patterns of performance between ETN and HTN patterns in Experiments 4 & 5. However, these were not seen in Experiments 6 & 7. There was a nameability effect and a condition crossover effect for older adults in Experiment 6 that was not seen in Experiment 7. The pattern of cross-domain effects in the simultaneous, but not sequential tasks was also seen in the younger adults. The younger group demonstrated a nameability effect, and a positive effect on neutral pattern set performance from Namers in Experiment 6, but not Experiment 7. It therefore appears that presentation of the visual patterns task using simultaneous presentation is more amenable to domain-general methods of task completion than the sequential task. This corresponds with the involvement of memory for names in a visual object memory task for both young and old adults (Hartley et al., 2001). However, it must also be pointed out that Hartley et al. also found that verbal ability was related to spatial task ability in older adults. So the concept of verbal coding being of possible benefit to sequential task presentation for older adults cannot be completely discounted.

If verbal memory ability can be associated with visual memory ability in both young and older adults, how can different patterns of performance between age groups, such as the condition crossover effect in older adults and the Namer performance benefit in young adults be reconciled? These differences are especially difficult to interpret when taken alongside the overall nameability benefit seen by both age groups for ETN patterns over HTN patterns. One possible explanation would be to assume that there is a qualitative difference behind the recruitment of cross-modal resources for both age-groups. It may be that older adults are unable to inhibit the activation of non-task specific resources. The increased proactive interference seen in older adults may mean that whatever methods are successful for task performance in the first instance are
employed throughout the rest of an experiment. Conversely differing methods of task performance may be a conscious choice for younger adults. This would be especially likely if current task performance is less affected by previously presented information in the younger group.

A possible explanation for the task performance seen in older adults would be that an older adult who is presented with either the ETN or HTN patterns in the first instance would approach the task using visual encoding methods alongside either verbal short term encoding or possible activation of previous knowledge using verbalisation. In the ETN pattern set this would lead to improved performance. The activation of previous knowledge would lead to a continuation of this method of task performance throughout the remaining conditions in the task. However these non-visual methods would not produce an improvement in performance in the HTN pattern set. If the HTN pattern set were presented first, one would still expect perseverance at cross-modal encoding; this would ensure that there would still be a benefit of ETN patterns by the time of the final condition. However, the proactive interference of the first (HTN) condition, which is not receptive to verbal strategies, could be the key to the lower scores in the neutral condition for those older adults in the HTN First condition.

For the younger adults, it appears that cross-modal encoding is less affected by the initial pattern set presented, but is more affected by individual differences. As with the older adults there was a whole group main effect of nameability, but unlike the older adults, improved performance in the neutral patterns was a function of displaying a nameability effect, and not presentation order. Therefore it is suggested that as a group, younger adults who display cross-modal encoding through nameability do so in order to improve task performance. This may, or may not be a conscious strategy at task improvement, although the findings of Brown & Wesley (2013) suggest there is some self-knowledge about the mechanisms used for task completion. As a caveat to this suggestion, it is worth noting that younger adults who demonstrated a nameability effect in the sequential memory task were the ones to display the lowest neutral pattern scores. This suggests that it is the lower performing young adults that are likely to choose sub-optimal task strategies. For older adults any cross-modal encoding does not appear to improve performance, suggesting that this is a passive process which is
possibly shaped by the characteristics of information presented within the earliest conditions of an experiment.

These explanations are commensurate with a number of readings and findings presented within this thesis. If older adults are regularly demonstrating cross-modal encoding then this may explain the paucity of older age group task type x performance interactions seen in Experiments 4 and 5 of thesis. Again, this would be supported by the interactions between performance and task type seen in the younger adults. The concept of cross-modal encoding being employed to improve performance in younger adults fits with the visual bootstrapping effect (Darling et al., 2012), the SNARC effect (Dehaene et al., 2005), and the increased relation between simple and complex span tasks for higher abilities participants (Unsworth & Engle, 2006). Logie (2011), suggested that memory performance within the multiple-component model could remain domain-specific until storage of information over and above the capabilities of the short-term stores was required. The improved performance of the young adult Namers in Experiment 6 may be taken as evidence for this suggestion.

The effect of knowledge from prior conditions affecting older adults’ task performance is commensurate with the literature on directed forgetting and proactive interference discussed earlier in this chapter. The increasing set size span method used in these tasks would, according to Lustig et al. (2001) affect older adults by increasing proactive interference from smaller set sizes when more difficult larger sets are being presented. As a logical extension of this, it is likely that this proactive interference has been continued across tasks. This is compatible with older adults’ inability to inhibit irrelevant, previously presented information shown by Zacks et al. (1996).

In summary, the overall presence or absence of the nameability effect is similar between young and older adults when experiments use one presentation method. However, it appears that older adults’ task performance on two neutral pattern sets with simultaneous presentation is more affected by previously presented information than is the performance of younger adults. Conversely, younger adults’ task performance on the neutral pattern sets with simultaneous presentation is more affected by individual differences in the nameability effect, with a nameability effect suggesting higher overall performance. Evidence for cross-modal encoding seen in the
simultaneous task was not apparent in the sequential task for either age group; however, older adults may still demonstrate cross-modal effects in sequential tasks under optimal conditions (see Experiment 4). To return to the larger picture of this thesis, these results are commensurate with a passive generalised approach to visual memory tasks in older adults, and a task-specific adaptive approach in younger adults.
Experiment 8

Introduction

The final experimental study within this thesis assessed the possibility that older adults use an attentionally demanding, executive resource to maintain information during VPT performance. This was assessed by measuring both young and older adults’ maximum visual spans and measuring the effects of executive (random generation) and non-executive (articulatory suppression) interference tasks during repeated presentations of information at the level of, and at a level below each individual’s maximum span level.

The data gathered within this thesis have shown a number of different patterns of visual memory task performance in older adults compared to younger adults. In Experiments 1, 2, & 3 older adults were shown to demonstrate differential effects of articulatory suppression on visual task performance compared to younger adults. In Experiments 4 & 5 older adults demonstrated different patterns of performance when presented with visual tasks that are amenable to verbal encoding. In Experiments 6 & 7 it was shown that older adults can, but do not always show crossover effects from one experimental condition to another. The findings of Experiments 4 & 5 using the easy and hard-to name (ETN/HTN) versions of the VPT developed by Brown et al. (2006) have suggested that the VPT is not a measure of pure visual memory ability for either young or older adults. However, it appears that younger adults are more able to adapt the method of task performance depending on context and methods of presentation than their older counterparts. This was characterised by pattern set x presentation type interactions in young, but not older adults' performance.

There is a body of literature from outwith this thesis which suggests that both the behavioural and architectural mechanisms of visual memory performance employed by older adults do not match those used by younger adults. Hartley et al. (2001) demonstrated a greater relationship between visual task performance, and object-naming ability in older adults compared to younger adults. It was suggested that this was not a conscious active process employed by older adults, but a passive reactive
occurrence. Imaging data has shown patterns of activation that are commensurate with this funding. Reuter-Lorenz et al. (2001) and Rypma et al. (2001) both demonstrated over activation of the DLPFC (an area typically associated with executive function) in older adults during tasks that were typically used to assess performance in parietal structures.

The Scaffolding Theory of Ageing and Cognition (STAC) (Park & Reuter-Lorenz, 2009) suggests that this increased activation in frontal areas represents a compensatory behaviour in in older adults. As discussed earlier in this thesis, the key tenet of STAC is that older adults require greater, typically frontal activation, at lower levels of task complexity in order to maintain task performance when compared to younger adults. What the data seen so far cannot indicate is whether this change in the underlying mechanisms of task performance with age is a result of using the central executive component of the Baddeley (2000) working memory system to maintain task performance, or is the result of a reliance on non-attentionally demanding functions that possibly employ the use of the episodic buffer (Allen et al. 2006).

The discussion section of Chapter 3 within this thesis suggested that changes in visual short term memory performance in older adults could be framed within the primary/secondary memory (PM/SM) distinction outlined by Unsworth and Engle (2006; 2007a; 2007b). It may be that older adults experience a decrease in the storage capabilities of the primary memory system, and as such rely on secondary memory, which is aided by previously held knowledge and long-term memories, at a lower level of task performance than younger adults. This is commensurate with the theories outlined above. However, it still does not suggest whether there is an attentionally demanding executive cost to the manner of performance in visual memory tasks employed by older adults.

There is evidence from the literature to suggest that under certain conditions a level of executive recruitment is present in visuospatial memory tasks in young adults. Rudkin et al. (2007) demonstrated that a spatio-sequential visual memory task suffered from a greater level of interference from an executively demanding interference task (random generation) than from a static visual task. Brown and Wesley (2013) found that a randomised spatial tapping task was of greater detriment to the nameability effect in
the static VPT than either articulatory suppression, or non-randomised spatial tapping. This may therefore be the behaviour that older adults extend to all visual memory tasks as they increase in age.

This experiment will assess performance in the visual patterns task by measuring each participant for their maximum span, and then measuring the effects of both articulatory suppression, and random generation compared to control performance at each individual’s span, and at one level of memory load below span. This method of titration has been used in a series of experiments (Della Sala et al., 2010; Logie et al., 2004; Logie et al., 2007) which have demonstrated no specific dual-tasking effect for older adults. Therefore any effects of random generation in this study can be attributed to the executive component of the task, rather than the effect of dual-tasking. Random generation as an executively demanding interference task was used by Baddeley (1966a), who found that the need to monitor not just one’s output, but to maintain the goal of the task outlined by the experimenter allowed the task to interfere with executive processes. Random number generation (RNG), with a set of measureable scales to assess the distribution of pairs of responses was described by Evans (1978). This experiment uses a modified version of RNG and employs random month, rather than random number generation. Random month generation (RMG) allows for a greater variation in response output (12 options rather than 10), and also prevents the use of apparently random numerical sequences that may actually be known to the participant, but not the experimenter (such as telephone numbers). The quality of an individual’s random generation will be measured by RGCalc (Towse & Neil, 1998). This is a program based on the Evans (1978) distribution of paired responses in RNG, but can be adjusted for response sets with differing sizes.

It was expected that older adults will have lower overall visual pattern task spans than younger adults. Articulatory suppression is not expected to affect older adults in a different manner to younger adults. This expectation arising from the lack of age specific dual-task effects reported by Della Sala et al. (2010) and Logie et al. (2004; 2007). In the executive interference condition it is expected that if older adults are using an executively demanding resource in order to maintain VPT performance, then there will be a greater effect of RMG on performance in older adults compared to
younger adults. This experiment will focus only on simultaneous presentation of information, and will not look at sequential presentation. The reasons for this are twofold. The first being that the differential effects between young and older adults within this thesis have been more robust in studies using simultaneous presentation. The second being that, as this study is explicitly looking to interfere with memory performance, a level of memory performance that can be disrupted without reaching floor effects is needed. This level has not been reached by most of the older, and many of the younger adults in previous experiments.

Methods

Participants

Two groups of participants took part in the study. 16 younger adults (8 females, 8 males) aged 18-25 (mean = 21.56, SD = 2.06) and 16 healthy older adults (6 males, 10 females) aged 60-75 (Mean = 65.12, SD = 3.72, Mean MMSE = 29.13, SD = 1.02). The younger participants had a mean education level of 2.58 (SD = .78). The older participants had a mean education level of 2.79 (SD = .51). There was no significant difference in education level between young and older adults, t (30) = -1.3, p = .19. Younger adults were recruited through the University of Edinburgh part-time recruitment website, or were taking part for course credit. Older adults were recruited from the University of Edinburgh volunteer panel. All participants were paid £5 for their time (other than those taking part for course credit), and all reported normal, or corrected-to-normal vision.

Materials

Participants were presented with the patterns from ‘neutral pattern set 1’ used in Experiment 6 for the initial span assessment. Pattern sets for assessment of interference at span level were developed using a random number generator and fixed for all participants. Squares within each pattern set measured 150 x 150 pixels. Participants responded by touching the screen and a stylus was provided for anyone who had
difficulties extending digits to press the screen. The experiment ran on E-Prime 2.0 software.

**Design**

The design was a 2 (Age Group) x 2 (Memory Level – At/Below Span, repeated measures) x 3 (Interference- None/Articulatory Suppression/Random Month Generation, repeated measures).

**Memory task**

The procedure from previous versions of the VPT used in this thesis was followed. After satisfactory completion of a practice phase at the lowest level of memory load (4 squares to recall, at least 2 out of 3 pattern sets completely correct), participants began the full VPT procedure. Each memory level began with a screen indicating the overall number of squares in the presentation grid and the number of squares to be recalled. Participants tapped the screen to continue. This was followed by a 500ms fixation cross and then a 3000ms presentation of the to-be-remembered pattern. This information was followed by a 10000ms blue screen. After this a blank version of the original grid was presented and participants were required to recreate the original pattern by touching the screen to turn the desired squares black. Participants were unable to delete squares once chosen; the response screen would remain until participants had entered the requisite number of squares. After this, participants would be shown a ‘break’ screen; they were instructed to tap this screen when ready to continue, the program then returned to fixation cross and the presentation of new ‘to-be-remembered’ information. After 3 presentations at any given pattern level participants were informed that they would be moving to a new grid and informed of the number of squares to be recalled. Span level was reached when a participant could no longer recall 2 out of 3 patterns completely correctly. Span scores were defined as the mean number of squares in the last 3 correctly recalled patterns. Once span level had been measured participants repeated the visual patterns task procedure with 10 patterns at a given number of squares. This was repeated with patterns at a participant’s span, and at a level 1 square below a participant’s span. Performance was calculated as a percentage of the possible number of squares correctly recalled.
Interference tasks

Articulatory Suppression
Participants were instructed to repeat the months ‘June’ and ‘July’ alternately. During practice tasks participants were trained to repeat one month per second. Once participants had reached a satisfactory level they were told to attempt to maintain this rate of repetition for all trials. Rate of repetition was taken as a measure of performance. The repetition of months was chosen in order to keep the spoken output of the suppression and random generation tasks as similar as possible. June and July were chosen at random and were used for all participants. This was a repeated measures variable. Participant’s performed suppression at, and at one level below their memory span.

Random Month Generation
Participants were instructed to say months from the Gregorian calendar in as random an order as possible. Participants were discouraged from repeating sequences, or pairs of months. The specific instructions asked participants to repeat months in ‘as broad and varied an order from the calendar as possible’. Participants were trained to utter one month per second. Performance was measured as total number of utterances, and ‘randomness’ was measured using RGCalc (Towse & Neil, 1998). This was a repeated measures variable.

Procedure
All participants initially undertook the VPT in order to ascertain their visual span. Once a span level had been determined, participants undertook 6 more iterations of the VPT that involved 10 presentations of patterns at a particular span level. Three of these were performed at the individual’s span level, and 3 were performed at 1-item below the individuals span level. This was counterbalanced between participants. At each memory level (at-span/below-span) participants performed random month generation, articulatory suppression, or the silent control condition. The interference tasks were performed in the 10000ms retention interval between presentation and recall. The
order of interference tasks was counterbalanced between participants. Each participant completed the interference tasks in the same order at both memory span levels.

Results

Span Measurements

Younger adults had a mean span of 9.81 \((SD = 1.78)\) (9.81 squares in the highest level of memory load successfully reached) and older adults had a mean span of 7.40 \((SD = 1.77)\). Younger adults had a significantly higher mean span than older adults, \(t(30) = 3.86, p < .01\).

Effects of interference tasks on memory performance

A 2 (age group) x 2 (Memory load) x 3 (Interference task) mixed ANOVA was conducted to assess the effects of interferences tasks on performance in the visual patterns task at different memory loads. Participants performed the VPT at and at one level below their maximum span. Performance was measured as the percentage correct of all to-be-remembered squares. There was no effect of age-group, \(F(1,30) = .703, p = .41, \eta^2_p = .023\). There was a main effect of memory load, \(F(1,30) = 20.73, p < .01, \eta^2_p = .41\). Bonferroni adjusted pairwise comparisons showed that memory performance was higher in the ‘below-span’ condition compared to the ‘span’ condition \((p < .01)\). There was a main effect of interference task, \(F(2,60) = 157.50, p < .01, \eta^2_p = .84\). Bonferroni adjusted pairwise comparisons showed performance in all 3 tasks differed from each other \((all \: differences \: p < .01)\). There was a memory load / interference task interaction, \(F(2,60) = 35.22, p < .04, \eta^2_p = .11\). Bonferroni adjusted comparisons within each memory level showed that all three tasks differed from each other in both the at-span condition, and in the below-span condition \((all \: p < .001)\). Bonferroni adjusted between groups comparisons showed that there was no difference in performance between memory loads in the single task condition, \(t(31) = -1.94, p = .06\), but memory performance was significantly lower in both interference conditions at the at-span level compared to the below span level \((AS: \: t(31) = -2.64, p < .01)\).
(RMG: \( t (31) = -4.89, p < .001 \)). Crucially, age group did not interact with either memory load, \( F (1,30) = 1.14, p = .29, \eta^2_p = .04 \), or interference task, \( F (2,60) = 2.64, p = .08, \eta^2_p = .08 \). There was no 3-way interaction between memory load, interference task, and age group, \( F (2,60) = .09, p = .91, \eta^2_p = .01 \).

**Fig 4.5** Mean percentage correct on VPT performance at and below-span in different interference tasks. Error bars represent Standard Error of the Mean.

Effects of memory load on interference task performance

A two-way mixed ANOVA was conducted to assess the effect of memory load on the rate of repetition in the articulatory suppression interference task. Younger participants had a mean repetition rate of 12.14 utterances in 10 seconds (\( SD = 3.09 \)) items at span and 12.32 (\( SD = 3.10 \)) items below span. Older adults had a mean repetition rate of 11.78 (\( SD = 3.18 \)) items at span and 11.67 (\( SD = 2.97 \)) below span. There was no effect of memory level, \( F (1,30) = .02, p = .89, \eta^2_p = .01 \), or age group, \( F (1,30) = .23, p = .64, \eta^2_p = .01 \). There was also no memory load x age group interaction, \( F (1,30) = .33, p = .57, \eta^2_p = .01 \) (See table 4.3 for mean AS utterance rates).
<table>
<thead>
<tr>
<th>Age group</th>
<th>Memory Load</th>
<th>Utterance rate</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td>At Span</td>
<td>12.14</td>
<td>3.09</td>
</tr>
<tr>
<td></td>
<td>Below Span</td>
<td>12.32</td>
<td>3.10</td>
</tr>
<tr>
<td>Older</td>
<td>At Span</td>
<td>11.78</td>
<td>3.17</td>
</tr>
<tr>
<td></td>
<td>Below Span</td>
<td>11.67</td>
<td>3.01</td>
</tr>
</tbody>
</table>

Table 4.3: Mean AS utterance rates for Young and Older adults in a t-span and below-span conditions during 10 second maintenance period

A two-way mixed ANOVA was also conducted to assess the effect of memory load on the rate of utterances in the random month generation task. Younger adults had a mean repetition rate of 7.01 (SD = 1.51) items at span, and 6.99 (SD = 1.72) items below span. Older adults had a mean repetition rate of 6.82 (SD = 1.49) items at span and 6.94 (SD = 1.68) items below span. There was no effect of memory load on utterance rate, \( F(1,30) = .13, p = .72, \eta_p^2 = .01 \), or age group, \( F(1,30) = .05, p < .83, \eta_p^2 = .01 \). There was no memory load x age group interaction, \( F(1,30) = .20, p = .66, \eta_p^2 = .01 \) (See table 4.4 for mean RMG utterance rates).

<table>
<thead>
<tr>
<th>Age group</th>
<th>Memory Load</th>
<th>Utterance rate</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td>At Span</td>
<td>7.01</td>
<td>1.51</td>
</tr>
<tr>
<td></td>
<td>Below Span</td>
<td>6.99</td>
<td>1.72</td>
</tr>
<tr>
<td>Older</td>
<td>At Span</td>
<td>6.83</td>
<td>1.49</td>
</tr>
<tr>
<td></td>
<td>Below Span</td>
<td>6.94</td>
<td>1.67</td>
</tr>
</tbody>
</table>

Table 4.4: Mean RMG utterance rates for Young and Older adults in at-span and below-span conditions during 10 second maintenance period

Towse and Neil’s (1998) RGCalc program was used to calculate the ‘randomness’ of paired responses in the RMG task. This is calculated based on a likelihood of contiguous responses in any given sequential set of labels/values. Pairs of responses that are further away from the expected sequence (Such as January, August, compared to November, December are less likely and therefore more random. The outcome is a
score between 0 and 1, with 0 being perfectly equal, random distribution and 1 being completely predictable patterns of responses.

A 2 (age-group) x 2 (RMG response at each memory load) ANOVA was conducted. There was no main effect of age group, $F(1,30) = .081, p = .777, \eta^2_p = .01$. There was no main effect of memory load on responses, $F(1,30) = .13, p = .74, \eta^2_p = .01$. There was a memory load x age group interaction, $F(1,30) = 4.73, p < .04, \eta^2_p = .14$. However, Bonferroni adjusted t-tests showed that there was no significant difference in RMG score at or below span within each age group (Young adults, $t(15) = 1.57, p = .14$) (Older Adults, $t(15) = -1.55, p = .14$). There was also no difference across age groups at each span level (At span, $t(30) = 1.71, p = .10$) (Below Span, $t(30) = -.97, p = .34$) (See table 4.5 for RMG scores).

<table>
<thead>
<tr>
<th>Age group</th>
<th>Memory Load</th>
<th>Random Generation Score (0-1)</th>
<th>SD</th>
</tr>
</thead>
<tbody>
<tr>
<td>Young</td>
<td>At Span</td>
<td>.244</td>
<td>.054</td>
</tr>
<tr>
<td></td>
<td>Below Span</td>
<td>.213</td>
<td>.047</td>
</tr>
<tr>
<td>Older</td>
<td>At Span</td>
<td>.201</td>
<td>.085</td>
</tr>
<tr>
<td></td>
<td>Below Span</td>
<td>.243</td>
<td>.116</td>
</tr>
</tbody>
</table>

**Table 4.5:** Mean RMG scores for Young and Older adults in at-span and below-span conditions during 10 second maintenance period

**Discussion**

Young and older adults’ performance on the VPT at different levels of memory load, with executive and verbal interference tasks was measured. Younger adults displayed higher overall spans than older adults. However, when the level of memory load was titrated for individual task performance there was no effect of age-group on memory performance. There was a main effect of memory load for both age groups. Participants displayed higher memory scores (as a function of percentage correct recall) in below-span memory conditions, compared to at-span memory conditions. There was also a main effect of interference task. Performance in the executive...
interference condition was lower than in the verbal interference condition, which in turn was lower than in the no interference condition. There was a memory load x interference task interaction. Both interference tasks had a greater effect on memory performance in the at-span condition than in the below-span condition. Crucially, however, there were no age-group interactions with either memory load, or interference task. This suggests that despite the differences in patterns of performance in visual memory tasks between young and older adults seen earlier in this thesis, the method of maintaining visual information that is employed by older adults is no more executively demanding than the method employed by younger adults.

There were no age differences in performance levels on the interference tasks. The rate of utterance in both the articulatory suppression and RMG tasks was not affected by memory load for either group. There was no main effect of age or memory load on the randomness of utterances in the RMG task. There was an age group x memory load interaction, however further comparisons did not reveal any significant differences within or between groups.

The data from this study are at odds with the work seen throughout this thesis which suggests that older adults employ different mechanisms to those employed by younger adults in order to complete visual short-term memory tasks. There are a number of possible explanations for this. The first relates to the method of measurement of the task being undertaken. In this experiment participants were being tested repeatedly at a fixed level of task demand, whereas the other studies have used an ascending set size for presentation. The second relates to the nature of the material presented. The age related effects in Experiments 4, 5 and 6 may have been due to the differences within the ETN/HTN pattern sets used. Experiment 8 is the first experiment in this thesis to use the computerised version of the VPT without using the ETN/HTN patterns. The final reason relates to the hypothesised mechanism that is associated with any changes in patterns of performance. For this experiment it was hypothesised that there was an increased level of attentionally demanding, executive recruitment employed by older adults in visual task performance. The data here suggest that this may not be the case.

The previous studies within this thesis have assessed any changes in patterns of performance between young and older adults as participants perform visual tasks with
ever increasing set sizes, and therefore task complexity, until participants can no longer correctly recall a set level of information. Under these conditions participants would never experience more than 3 presentations of any visual stimulus at any given size before the task either concluded, or they were moved on to the next level of recall. In this experiment however, once participants had been measured for their individual span, they could expect 30 (10 in each interference condition) presentations at a given level of complexity before moving onto a new level of complexity. Performing a task at the same level of difficulty for 30 trials may represent a different set of demands than a task which increases the level of difficulty after every third trial. It may be that the mechanisms older adults use to achieve maximum task performance are different from those used to maintain task performance at a given level. Sander et al. (2011) found that increased presentation time in a binding task would eventually benefit older adults as much as it benefitted younger adults, but it would take older adults longer to experience these benefits. Hartley et al. (1990) also found that older adults were slower to switch between two tasks than younger adults. Undertaking visual memory tasks at different levels of performance is not necessarily akin to task switching. However, these findings suggest that older adults are slower to adapt to any changes in task requirements and this might exacerbate differences between age-groups in ascending set size experiments, therefore reducing any differences in interference task patterns when there is repeated performance at the same level of task difficulty.

The material presented in this study was not intended to guide participant performance in the same manner as the ETN/HTN pattern sets used in previous studies. The data seen in Experiment 6 suggest that older adults’ method of visual pattern task performance is affected by the nature of the first set of patterns presented to them. It is unclear what causes this effect, but it may direct a participant towards a non-visual method of recall which aids subsequent performance. If, as happened in this experiment, participants are not presented with a set of patterns which is intended to direct performance in this manner, then there may be a loss of the differences in performance seen between young and older adults.

Finally, this study hypothesised that older adults used an executively demanding mechanism to maintain visual task performance. This hypothesis arose from the STAC
theory (Park & Reuter-Lorenz, 2009), and imaging data (Banich, 1998, Rypma et al., 2001) which suggested that older adults demonstrate greater bilateral recruitment of frontal areas, such as the DLPFC in order to complete tasks than do younger adults. This was corroborated by behavioural data from this thesis (Experiment’s 4, 5 & 6), as well as from Johnson et al. (2010) which suggests that older adults use generalised, rather than specific task resources in order to carry out visual tasks. Whilst there is still the body of data suggesting that patterns of performance are more generalised in older adults, there is no evidence from this experiment suggesting that this is due to a reliance on attentionally demanding executive resources. It is therefore possible that older adults employ the episodic buffer to a greater extent than younger adults do. Baddeley et al. (2011) suggested that the episodic buffer could be employed without attentional control. Therefore older adults may be more reliant on previous task performance, or relevance of information to previously held knowledge that is automatically activated in the episodic buffer by presentation of visual information. Logie, (2011) speculated that episodic buffer activation could be cost free in healthy older adults, but may require control in those with Alzheimer’s. A reliance on the episodic buffer could be seen as being analogous to an increased reliance on the secondary memory system proposed by Unsworth and Engle (2006), who suggested that these two constructs, with their activation of long-term memory to aid short-term memory may be functionally similar.

The absence of differences in performance between young and older adults when there is interference in the retention interval of a task suggest that any differences arising in patterns of visual task performance between young and older adults arise either at the encoding stage of information, or are directed by the nature of the material presented. If the nature of material presented affects older adults’ performance, this suggests that the VPT is not a process pure measure of performance for older adults. The lack of executive interference over and above that seen in younger adults suggests that any difference is not due to an increased use of an attentionally demanding mechanism. Therefore it is suggested that differences in performance may be due to cost-free use of the episodic buffer. Short-term memory performance may be linked to previous knowledge on task completion or previously presented information. This idea is commensurate with data suggesting that older adults suffer greater interference from
previously presented information when attempting to complete memory tasks (Anderson et al., 2011; Sahakyan et al., 2008). This is turn is commensurate with the suggestions of Unsworth and Engle (2006) that retrieval from secondary memory is subject to proactive interference. Taken together, this provides some evidence for the possibility that older adult visual task completion is not a process whereby older adults choose to perform tasks in a non-visual manner through the assignment of executive resources, but is a process where a decline in short-term memory storage leads to a passive activation of longer-term knowledge in either secondary memory or an episodic buffer.
Chapter 5

Summaries and Conclusions

The introductory chapter of this thesis covered five key areas which led to the development of the general hypothesis. The five areas discussed were the need to reject the ‘dull’ hypothesis of ageing (Perfect & Maylor, 2000), the differences between three major models of working memory (The Multiple Component Model: Baddeley & Hitch, 1974; Baddeley, 1986, 2000; Logie, 2011. The Embedded Processes Model: Cowan, 1988, 2005. Primary/Secondary Memory: Unsworth & Engle, 2006, 2007a, 2007b), the differences between three major models of cognitive ageing (Salthouse, 1996; Hasher & Zacks, 1988; Park & Reuter-Lorenz, 2009), process impurity and domain generality in working memory task performance, and the changing interplay of separable working memory components with age. The general hypothesis was that there will be age-related decline in short-term visual memory task performance and that this change would be accompanied by an increase in the use of verbal codes to complete visual tasks in older adults. This chapter reviews key findings from this thesis in the summaries section and addresses these findings in relation to the five key areas, as well as suggesting directions for future research in the conclusions section.

Summaries

Differential effects of Articulatory Suppression

Chapter 2 of this thesis used three experiments to assess differences in the effects of articulatory suppression on visual memory task performance between young and older adults. The first of these three experiments was an attempt to replicate the findings of Brandimonte et al. (1992). In young adults Brandimonte et al. had found that there was a positive effect of articulatory suppression on performance in a mental image rotation task. This effect was only found when the to-be-rotated images were easy to name. Brandimonte et al. had originally concluded that this finding represented a verbal
overshadowing effect, where unnecessary verbalisation of visual images inhibited performance on the visual task. This finding had not been replicated by Alnajashi et al. (2007), so the study within this thesis sought to clarify this effect, as well as explore the possibility of differences in performance between young and older adults. The findings with younger adults broadly replicated those of Alnajashi et al., not Brandimonte et al. in finding a negative effect of articulatory suppression on performance. There was a partial replication of the Brandimonte et al. findings in the older age group. Older adults demonstrated the positive effect of suppression in the easy to name condition that was seen in the original study. However, there was also a negative effect of suppression in the difficult to name condition.

The data seen in this initial study created more questions than answers. There was a level of verbal activation for both young and older adults in visual memory task performance. This was evidenced by the effects, both positive and negative, of articulatory suppression on task performance. There were however differential effects of suppression on task performance between the two age groups. The negative effect of suppression on younger adults suggested that verbal coding is beneficial to younger adults. The mixed effects of articulatory suppression in the older group suggested that verbal coding is not always beneficial to older adults, but that this does not prevent its activation. This is commensurate with the inhibition deficit hypothesis of ageing outlined by Hasher and Zacks (1988), and with the behavioural patterns seen by Hartley et al. (2001) where older adults show a greater relationship between verbal and spatial task ability than their younger counterparts.

Experiment 2 was conducted in order to assess interference effects in visuospatial and verbal task performance in older adults. The double dissociation of visual and verbal task performance in younger adults is a robust finding from within the working memory literature (Cocchini et al., 2002; Farmer et al., 1996; Logie et al., 1990). When performing two tasks designed to tap the same memory domain, without exceeding the level of ability in either individual task, participants will show a greater decline in memory performance than when performing two tasks designed to tap separate memory domains. However, there is also process impurity in working memory tasks, where cross-modal encoding from separate domains can be of benefit to task
performance (See Brown et al., 2006, and the nameability effect. See also Darling et al., 2012 and visual bootstrapping). What was in question in Experiment 2 was whether there was a change in the patterns of selective interference between young and older adults. Participants undertook a visuospatial working memory task (The Miyake & Shah, (1996) letter ‘R’ task) and a verbal working memory task (Baddeley et al. (1985) version of the WM span task). Both of these tasks were performed twice using an ascending set size presentation method. In a repeated measures design participants undertook either articulatory suppression or a spatial tapping task during a ten second maintenance period between encoding and retrieval. Performance was measured as the total number of items correctly recalled. The younger adults demonstrated the classic double-dissociation. Interference tasks had a greater negative effect on performance in memory tasks from the same domain. This was not seen in the older adults. Performance in the verbal task matched those of the younger adults. There was a greater decrement in verbal memory performance when performing articulatory suppression in the retention interval compared to performing the spatial tapping task in the retention interval. However, in the visuospatial task, older adults demonstrated no difference in performance when performing either suppression, or the spatial tapping task. The data from Experiment 2 therefore supported the robust findings of a double dissociation of visual and verbal task performance in younger adults. In line with Johnson et al. (2010) the data also suggested an increase in the use of general abilities in the performance of visuospatial tasks for older adults. This led to the formation of the research question explored in Experiment 3. What is the specific mechanism of visuospatial memory (the visual cache or inner scribe) that is most susceptible to verbal interference in older adults?

Logie (1995) posited two separable sub-components of visuospatial working memory. These were a visual cache that was recruited for storage of static visual images, and an inner scribe which was involved in the rehearsal of spatial and sequential information. Logie and Pearson (1997), and Della-Sala et al. (1999) demonstrated through selective interference tasks that these were separable components in younger adults. Experiment 3 assessed both young and older adults on two versions of the VPT. The first used simultaneous presentation of static patterns and was designed to measure the visual cache. The second used sequential presentation of patterns and was designed to
measure the inner scribe. Individuals undertook 4 experimental conditions (both simultaneous and sequential presentation with and without articulatory suppression) to ascertain if older adults experienced a greater negative effect from suppression than young adults, and if there was an interaction between task type and suppression effect in the older group. The outcome measure was the participant’s maximum span.

In the younger group there was no effect of articulatory suppression on performance in either version of the visual task. In the older group there was a general negative effect of suppression on task performance. This provided further evidence for a level of verbal coding in visual task performance in older adults. There was also a greater effect of suppression on sequential task compared to the simultaneous task performance in older adults when comparing relative decline between single and dual-task conditions.

The general trend of these three experiments was that there is indeed a difference in the effect of articulatory suppression on visual task performance in older adults compared to younger adults. Older adults showed effects of articulatory suppression in all experiments. In the short-term memory tasks used in Experiments 2 and 3 this effect was negative, and appeared to be pervasive across all tasks. In the longer term memory task in Experiment 1, this effect was negative when patterns were hard to name and positive when patterns were easy to name. In younger adults there was no effect of suppression on visual task performance in Experiment 3, but there was a negative effect on performance in Experiment 1. This suggests that the recruitment of a verbal ability in visual task performance does occur in younger adults, but it is not as common, or possibly as necessary as it is for older adults. In the short term visual memory tasks of Experiments 2 and 3 there was no evidence to suggest that younger adults used any form of verbal encoding. In the longer term memory task of Experiment 1, it is apparent that it is used, and it benefits performance (as evidenced by the negative effect of articulatory suppression).

It is suggested that in longer-term visual memory tasks, such as that used in Experiment 1, there is a level of verbal encoding recruited by both young and older adults. This may be a result of the amount of time available for rehearsal, or the time available to link the presented information to long-term knowledge. In short-term
memory tasks there appears to be a greater recruitment of verbal abilities for older compared to younger adults. From the data seen in these three experiments it is unclear why this is the case. The data seen do support the increase in generalised visual task performance outlined by Scaffolding Theory (Park & Reuter-Lorenz, 2009) that was demonstrated by Chen et al. (2002) and Johnson et al. (2010). The positive effect of suppression in the easy to name condition of Experiment 1 suggested that verbal coding of a visual task is prevalent in older adults even when it is not of benefit to task performance. This may be an example of an inability to inhibit information hypothesised by Hasher and Zacks (1988) and as seen by Hartley et al. (2001) with an increase in the relationship between verbal and spatial task ability in older adults.

Cross-Modal task performance in the Visual Patterns Task

The first three experiments of this thesis ascertained that there are differences in the effects of articulatory suppression on visual task performance for young and older adults. Experiments 4 and 5 of this thesis measured differences between task performance on visual tasks that were modified in order to encourage cross-modal encoding of information. Both experiments used the stimuli from the Brown et al. (2006) VPT. These were the stimuli from the Della-Sala et al. (1999) version of the task specifically divided into two distinct pattern sets based on the number of verbal labels that could be ascribed to each individual pattern. Patterns with a higher number of verbal labels were placed in the easy-to-name (ETN) set, whilst patterns with fewer labels were placed in the hard-to-name (HTN) set. Brown et al. demonstrated that visual performance was significantly higher in the ETN pattern set compared to that in the HTN set (the nameability effect) in younger adults. It was concluded that this difference was due to the level of available verbal encoding, and that a multimodal representation of information presented in the VPT can improve task performance.

Scaffolding Theory (Park and Reuter-Lorenz, 2009) posits that there will be greater cross-modal task performance with age, and that this may be a response to the declining visual task ability seen in older adults (Logie & Maylor, 2009; Park et al., 2002). Experiments 4 and 5 used a repeated measures design to assess young and older adults’ performance in the ETN and HTN versions of the VPT using both simultaneous and sequential presentation methods (as seen in Experiment 3 of this thesis). The only
difference between the experiments was the nature of the sequential presentation. In Experiment 4 the sequential presentation of information followed a set pattern, where to-be-remembered information was always presented from left-to-right along each row in a visual matrix. In Experiment 5, there was no set method of presentation. Each square from within pattern was presented in a random-order (and fixed for all participants). Parmentier et al. (2005) had suggested that the nature of sequential pathway presentation could affect performance in young and older adults, and this manipulation allowed for this to be assessed.

In Experiment 4 younger adults replicated the findings of Brown et al. (2006) and Brown and Wesley (2013) by demonstrating a nameability effect in the simultaneous version of the task. This effect was not seen in the sequential-ordered version of the task. The older adults also showed a nameability effect in the simultaneous task. However, this was accompanied by a nameability effect in the sequential-ordered version of the task. In the sequential task, participants never saw the overall image that was presented; information was presented one square at a time. Despite this it appeared that the qualities which led to a benefit in task performance from the ETN pattern sets in the simultaneous task also led to a benefit for older adults in the sequential ordered version of the task. It was hypothesised that a verbal approach to a sequential visual task (as demonstrated by older adults in Experiment 3) may be benefitted by the production of the pattern which is easy to name, rather than the more abstract, hard-to-name patterns.

In Experiment 5, where there was the sequential-randomised presentation, younger adults demonstrated the same patterns of performance that were seen in Experiment 4. That is, there was a nameability effect in the simultaneous task, but not in the sequential task. Unlike in Experiment 4, there was no nameability effect for older adults in either version of the VPT. It appeared that the introduction of a sequential-randomised version of the VPT had removed the nameability effect for older adults in not just the sequential, but the simultaneous version of the task.

The young adults had demonstrated a nameability x presentation type interaction in both experiments. The older adults had demonstrated either an overall nameability effect, or no nameability effect, but never a nameability x presentation type interaction.
This led to the conclusion that older adults demonstrate greater generalised task performance that is affected by not just the nature of the stimuli presented in one experimental condition, but the nature of tasks within any given experiment. This then began to suggest that the changes in older adult task performance, whilst using phonological codes, were not based purely on verbal recoding of the visually presented information in front of the participant. This was commensurate with Brown and Wesley (2013) who had demonstrated that the nameability effect was not a simple act of phonological recoding, but possibly related to executive recruitment. This was shown by selective interference on the nameability effect from randomised tapping tasks, but not articulatory suppression. The data seen in these experiments suggest that there is an element of long-term or previously held knowledge regarding a given memory task that accounts for some portion of older adult visual task performance. This might be through the active recruitment of executive resources, or it may be through automatic recruitment of a mechanism such as the episodic buffer (See Darling et al. 2012, for an argument for episodic buffer activation during a short-term verbal memory task). This episodic buffer activation hypothesis has some parallels with the system of primary (PM) and secondary memory (SM) outlined by Unsworth and Engle (2006). In both systems older adult task performance could be characterised by a decline in short-term visual storage capacity (see Logie & Maylor, 2009), and a reliance on a secondary system which activates previously held knowledge or semantic information on methods of task performance. The absence of nameability x task type interactions in younger adults is commensurate with an increase in generalised visual task performance (suggested by Park & Reuter-Lorenz, 2009), as well as a possible loss of the ability to inhibit irrelevant task mechanisms (Hasher & Zacks, 1988). From these data it was decided that future research should address two questions. The first concerned the nature of cross-condition effects in young and older adults. Does the presentation of ETN or HTN pattern sets in the opening condition of an experiment affect task performance? The second concerned the possibility that older adults were actively recruiting executive resources in order to improve, or maintain visual task performance.
Cross-Condition performance in the Visual Patterns Task

The data seen in Experiments 4 & 5 suggested that older adult task performance could be affected by not just the experimental task being undertaken, but by the nature of all the conditions within an experiment. Therefore two experiments, one assessing performance in the simultaneous VPT, and one assessing performance in the sequential-ordered version of the VPT were conducted in order to assess the possibility of cross-condition interference, the robustness of the nameability effect to any such effects, and whether the presence of a nameability effect was an indicator of improved overall task performance in young and older adults. Participants took part in either the simultaneous or sequential-ordered experiments. Other than the nature of the presentation method, the design was matched for both experiments. Participants would initially undertake either the ETN or HTN version of the VPT. They would then undertake the task using two neutral pattern sets. In the final condition they would complete the VPT using whichever of the ETN or HTN pattern sets that had not been used in the first condition.

The experimental literature suggested that older adults are more likely to suffer from proactive interference (Anderson et al., 2011) and are less efficient at forgetting previously presented information (Sahakyan et al., 2008) than younger adults. This led to the hypothesis that older adult performance on the two neutral pattern sets would be affected by presentation of either ETN or HTN patterns in the opening experimental condition. This effect was seen in the data for the simultaneous task. Older adults who had seen the ETN patterns in the first condition demonstrated significantly higher performance in the neutral pattern sets compared to those who had started the experiment with the HTN pattern set. This effect was not seen for the younger adults, nor was it seen for either age group in the sequential-ordered task.

There was an overall nameability effect for both young and older adults in the simultaneous version of the task. However, this was not seen in the sequential task. The simultaneous nameability effect was seen regardless of the presentation order of ETN/HTN patterns. This suggests that the inherent characteristics of the patterns, as selected for by Brown et al. (2006) are distinct enough to lead to a nameability effect.
even in the presence of presentation order effects such as those seen in this experiment. In both the simultaneous and sequential-ordered data set, participants were divided into two groups based on whether they had demonstrated a nameability effect or not. In the simultaneous task, young adults who had demonstrated a nameability effect displayed improved neutral pattern set scores. This was not seen for the older group, and no effect was seen at all in the sequential-ordered experiment. The finding in the simultaneous task was commensurate with the hypothesis that cross-modal encoding of the VPT is beneficial to younger adult task performance (as demonstrated by Brown & Wesley, 2013), but can only maintain, not improve task performance in older adults (as suggested by Park & Reuter-Lorenz, 2009).

There were three key findings from these two experiments.

1) In the simultaneous task, older adults demonstrated improved performance on two neutral pattern sets when presented with the ETN pattern set first. This suggests that there is cross-conditional task performance, and proactive interference (albeit, in some cases, possibly beneficial) in older adult VPT performance

2) There was no replication of the sequential-ordered nameability effect in older adults that was seen in Experiment 4. This suggests that any cross-modal performance effects seen in the sequential tasks in Experiments 4 & 5 may be due performing the sequential task alongside simultaneous version of the VPT

3) In the simultaneous task, cross-modal task performance was an indicator of higher overall performance in the younger group. This was not the case in the older adults.

The data seen here are in line with the hypotheses of greater generalised task performance in older adults (Chen et al., 2002; Park & Reuter-Lorenz, 2009) where cross-modal performance does not necessarily improve performance, and a task specific adaptive approach combining both primary and secondary memory systems in younger adults (Unsworth & Engle, 2006; 2007a; 2007b).
Executive recruitment in visual tasks

The final experiment within this thesis sought to measure whether there is an increased level of executive recruitment in VPT performance in older adults compared to younger adults. There is evidence from the experimental literature which suggests that there is executive recruitment in simultaneous (Brown & Wesley, 2013) and sequential (Rudkin, et al., 2007) versions of the VPT with younger adults. The increases in older adult generalised task performance seen in this thesis suggest that there may be increased executive recruitment in an older age group.

Participants were assessed for their maximum VPT span and then asked to perform repeated trials at, and at one level below their span. At each level of memory load participants performed an articulatory suppression, a random generation, and a no interference condition during a ten-second retention interval between presentation and recall. Performance in these conditions was measured by the percentage of squares correctly recalled in each interference condition. Crucially there were no age-group interactions in this experiment. Both age-groups showed a greater effect of interference at span, than at below span, and both age groups showed a greater effect of random generation, than of articulatory suppression. However, the magnitude of these effects remained constant across the lifespan. This suggested that both young and older adults do use executive resources to an extent when performing visual memory tasks, and that these resources are used to a greater extent when the task is performed at the limits of an individual’s memory capacity. However, there is no difference in the level of executive recruitment between age groups.

What then, is the explanation for the lack of age group effects in this study, when they have been present in all other studies within this thesis? One possible explanation is that all other studies in this work have measured interference tasks when participants were performing increasingly difficult memory tasks. In this study, participants were repeatedly performing tasks at the same level of memory load. There may be a qualitative difference in the methods engaged in task performance when recalling information from thirty trials at one level of memory load, rather than recalling from a new memory level every three trials.
The lack of age-related effects from the executive interference task suggest that any differences in performance between age groups that have been seen throughout this thesis cannot be ascribed to an active executive recruitment during a maintenance period. This suggests that changes in visual and specifically VPT performance are not due to executive recruitment. There is some level of verbal recoding present in visual task performance, and this can result in cross-modal and cross-conditional effects on task performance. These patterns are seen in both young and older adults. In younger adults they do not appear in all conditions, and when they do, they can be indicators of higher overall performance. In older adults they are more common, and do not necessarily contribute to any improvement in performance.

A Brief Recapitulation

1) Experiments 1-3 showed that older adults experience effects of articulatory suppression on performance in differing visual tasks. These effects have shown that verbal coding can be beneficial, or detrimental to task performance. Younger adults showed negative effects of articulatory suppression in Experiment 1, but not in Experiments 2 & 3.

2) For older adults cross-modal encoding is either present in all task conditions within an experiment, or in none (Experiments 4 & 5). For younger adults cross-modal encoding is apparent in simultaneous versions of the VPT, but not in sequential versions.

3) Task performance in a simultaneous VPT experiment for older adults appears to be directed by the nature of the first condition presented. There is still a group wide nameability effect. It is robust against presentation order, but it is not necessarily beneficial to task performance. Younger adult task performance is not affected by the nature of the first condition presented, and there is also a group wide nameability effect. However, the nameability effect is an indicator of higher overall task performance.
4) There is no greater level of executive recruitment for older adults compared to young on the simultaneous VPT. Any differences in task performance are not due likely to be due to executive recruitment during maintenance of to-be-remembered information.

Conclusions

The introductory chapter to this thesis outlined five points that were important to the development of the rationale. These points were revisited at the beginning of this chapter and each one in turn will be discussed here in order to provide a summary of the answers, and questions, provided by this thesis.

Rejecting the ‘Dull Hypothesis’.

The first point related to the need to reject the ‘dull’ hypothesis of a linear decline across all task abilities with age (Perfect & Maylor, 2000). The data within this thesis emphatically reject this dull hypothesis. Using the experimental/ANOVA approach it has been shown that older adults experience greater effects from articulatory suppression on visual tasks than their younger counterparts. This is prominent when performing visual tasks using an ascending set size presentation method. There is also evidence of cross-condition effects, where older adult performance on subsequent experimental conditions is affected by the nature of earlier tasks in an experiment. This is not seen in younger adults. It is clear from the data seen within this work, that there are non-linear declines in task performance with age, and that the manner in which older adults perform visual short term memory tasks is not always analogous to that of younger adults.

Differing models of working memory.

The second point related to different working memory models. As was stated in the introductory chapter, the aim of this thesis was not to provide evidence for or against any model of working memory. It is also pertinent to note, that whilst the embedded processes model of Cowan (1988, 2005) was discussed within the opening chapter, the
studies conducted within this thesis lent themselves to interpretation through the prism of the multiple component (Baddeley & Hitch, 1974; Baddeley, 1986; Baddeley, 2007; Logie, 2011) or Primary Memory/Secondary Memory (Unsworth & Engle, 2006, 2007a, 2007b) models. A valuable point discussed in the opening chapter, was the suggestion that many of the differences posited between working memory models were in fact differences in emphasis and research question, rather than differences in theoretical assumptions (Logie, 2011). With this in mind it is fitting that the data seen here are commensurate with a number of findings from both the multiple component model and the Primary/Secondary Memory distinction. Experiment 2 replicated the classic double dissociation of visual and verbal working memory (Cocchini et al. 2002; Farmer et al. 1996; Logie et al. 1990) in younger adults, whilst showing that, when measuring performance with increasing set sizes, this effect is not seen in older adults. Perhaps most importantly for any collaborative theory, Experiment 6 produced patterns of behaviour in the younger age group that were commensurate with claims made regarding both models of working memory. Cross-modal encoding of information was an indicator of higher overall task performance in younger adults. This corresponded with behaviours attributed to the episodic buffer (see Brown et al., 2006; Darling et al., 2012), but also to secondary memory (Unsworth & Engle, 2006). This suggests an overlap between constructs laid out within differing working memory models. What is also clear, is that the visual task performance seen in older adults represented a move away from the storage only mechanisms of any given model, and represented the use of other cognitive mechanisms, possibly recruited through the use of verbal codes.

Differing models of cognitive decline

The third point related to differing models of age-related cognitive decline. The opening chapter of this thesis discussed the Processing Speed Theory of Aging (Salthouse, 1996), the Inhibition Deficiency hypothesis (Hasher & Zacks, 1988), and the Scaffolding Theory of Aging and Cognition (Park & Reuter-Lorenz, 2009). The experimental data gathered within this thesis did not focus on timed tasks or reaction times. As such, it is difficult to interpret any work presented here through the prism of a processing speed related theory. For the other two models of cognitive ageing, there
are parallels with the conclusions reached regarding working memory models. That is that the data are commensurate with both the Inhibition Deficiency, and Scaffolding Theory models of ageing. The increase in domain general task performance with age as hypothesised by Park and Reuter-Lorenz has been seen in Experiments 2 and 3. However, this increased generalizability appears to be the result of a decline in the ability to inhibit the use of verbal codes (See Experiments 2 & 3 for interference effects, Experiment 6 for an effect of previously presented information). It was concluded that the increased generalizability of older adult visual task performance was a result of a lack of inhibition, rather than an active executive recruitment process for three reasons. Firstly, it was possible to improve older adults’ behaviour by removing the availability of verbal encoding (see Experiment 1). Secondly, the demonstration of cross-modal behaviour was not an indicator of higher overall task performance in older adults (Experiment 6). Finally, there were no age related effects of executive interference tasks on VPT performance. These three points paint a picture which suggests a change in older adult behaviour that is automatic, and not necessarily beneficial to overall task performance.

Variation in working memory performance

The issue of domain generalizability and variation within working memory task performance was also discussed. There is ample evidence within this thesis to suggest that the mechanisms which supplement visual short-term memory stores over and above the act of storing a visual representation of presented information. This has been shown by the repeated replications of the nameability effect in younger adults, as well as cross condition effects in older adults. There is still scope for research into individual differences within these phenomena, as there are individuals who do not demonstrate cross-modal effects. Within these studies this could be for a number of reasons, such as counterbalancing effects or familiarity with particular shapes in patterns that are unknown to the experimenter (a particular pattern could resemble an individual’s tattoo for instance). Future research could follow the lines of Brown & Wesley (2013), who questioned participants on the manner in which they performed tasks, as well as using behavioural outcomes.

Age related variation in working memory performance
The final area considered within the introductory chapter, and indeed, the crux of this thesis was the change in the relationship between separate memory abilities with age. The data presented in Experiments 1-6 of this thesis do show that there is a change in interference and task order effects in visual short term memory tasks with age. There are clear patterns of performance suggesting greater verbal recruitment during visual task performance by older adults when performing tasks using ascending set size presentations. There were only three occasions where older adults did not show differential interference effects compared to younger adults. In Experiment 2 young and older adults showed matching patterns of interference from articulatory suppression and a spatial tapping task when performing the working memory span task. This was hypothesised as Logie & Maylor (2009) had shown that there was relatively little verbal task decline across the lifespan (compared to visual task performance). Johnson et al. (2010) had also shown an increase in task specific variance on verbal tasks with increasing age.

In Experiment 7 there were no age group effects (other than overall task performance) in the sequential-ordered VPT. In this case young and older adults showed no nameability effect and no presentation order effect. This was the only experiment within the thesis to contain a sequential version of the VPT with no simultaneous version. It is possible that this had some bearing on the absence of cross-modal or age-related effects; however the exact mechanisms behind this remain unclear.

In Experiment 8 there were no age-related interference task effects between young and older adults. It is hypothesised that the nature of the task, with repeated trials at a given task level, leads to different patterns of behaviour than other tasks within this thesis. Experiments 2-7 all used ascending set size presentations where participants would see three pattern sets at any given level of complexity. If at least two out of three of these pattern sets were correctly recalled, then the participant would move on to the next level of complexity (usually a matrix that featured two extra squares, meaning there was one extra item to recall). If, as seen in Experiment 6, older adults are directed in their performance by previously presented versions of the task, then the methods of Experiment 8, where participants would see 30 trials using a visual pattern matrix at one given size, would lend themselves to improvements in older adult performance. A
constantly increasing set size may mean that an older adult’s verbal recruitment is used to rehearse rules about the number of items to be presented. A set size that is held at one size may allow an older adult’s verbal recruitment to be used for rehearsing characteristics of the presented information. This explanation is still compatible with an inability to inhibit verbal recruitment; however it also suggests that the use of this capacity can take more than one form, depending on the manner of the task.

To conclude…

The data seen here are commensurate with a decline in short-term visual storage capacity in older adults (as seen by Logie & Maylor, 2009; Park et al., 2002, and in the age group x performance interactions present in this thesis), an increased relationship between verbal and visuospatial abilities (see Hartley et al. 2001, and effects of articulatory suppression on older adult task performance in Experiments 1, 2, & 3), and an increase in the use of a mechanism relating to longer-term memory (possibly the episodic buffer, Darling, et al. 2012, or secondary memory Unsworth & Engle, 2006). Behavioural indicators of an increase in secondary memory recruitment include increased interference from previously presented information (Anderson et al. 2011, and Experiment 6). It is also likely that this is a passive change in behaviour that is not directly controlled through executive resources (Experiment 8), that does not necessarily benefit task performance (Experiments 1 & 6; see also Scaffolding Theory, Park & Reuter-Lorenz, 2009).

Future research into this area should seek to further define and measure episodic buffer/secondary memory function. The episodic buffer has been attributed as having no attentional cost (Allen et al., 2006), however it also been described as being possibly analogous to Cowan’s Focus of Attention (Baddeley, 2007, p153). Brown and Wesley (2013) and Darling et al. (2012) have hypothesised the episodic buffer as being a candidate mechanism for cost free (to executive resources) multimodal encoding. This is similar to the parameters of secondary memory such as semantic associations and context based memories that were outlined by Unsworth and Engle (2006). A reconciliation of these two systems through a series of selective interference tasks with clearly defined parameters for the abilities of a multimodal mechanism could help to provide a clearer idea of the mechanism behind cross-modal, non-executive function.
in not just older, but all adults. The data seen in this thesis suggest that verbal codes are undoubtedly used to a greater extent by older adults in visual task performance. However, there are patterns of behaviour, such as cross-condition effects which suggest that verbal codes are not used purely for rote rehearsal of presented information. The cross-conditional effects of Experiment 6 and the positive effects of articulatory suppression in Experiment 1 suggest that the increase in the use of verbal codes may represent a link between the storage of short and longer-term information that is used more frequently with increasing age.

The ultimate findings of this thesis are commensurate with Logie (2011) who suggested that working memory is indeed made of separable subsystems; however these act in concert to represent a single working memory. These systems are present in all healthy older adults, but the reliance on specific resources is different within individuals. This is evidently the case in older adult visual task performance where the balance between these separate components is altered, but still produces a functioning working memory system. To summarise, the data seen in this thesis can still be understood through the sporting analogy used in the opening paragraphs of this thesis. Young and older adults can still be taken to perform cognitive tasks in the same way two swimmers of differing ages would approach a race. The younger adults have separable resources such as stamina and technique to call upon. Depending on the nature of the task ahead they will recruit raw force and use the ‘stamina’ mechanism, or they will rely on a well-honed technique. If the task requires it, they will focus on swimming using both their technique and their stamina. Older adults may suffer from a decline in stamina (or in this thesis, visual short term memory capacity), but they retain their technique (or ability to use verbal codes). Without the need for an active recruitment of either system older adults may rely more on their technique than their stamina. This still produces a passable level of performance, but does not improve performance significantly above what would be expected from using the original task specific resources. What is necessary for future work is to understand specifically how this maintenance of technique (or the use of verbal coding) is used in healthy older adults.


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Appendices

Appendix A

Appendix A.1 Response sheet for Miyake and Shah (1996) Letter ‘R’ Task used in Experiment 2

Appendix A.2 Spatial tapping task response box used in Experiment 2
Appendix A.3 Stimulus box used in Experiment 3.

Appendix A.4 Experimental setup of Experiment 2. The individual on the left represents the experimenter, the individual on the right represents the participant.
Appendix B

Appendix B.1 Examples of ETN (left hand side) and HTN patterns from Brown et al. (2006) and used in Experiments 4-7. Participants’ task was to recall black squares.

Appendix B.2 Touchscreen experimental paradigm used in Experiments 4-8.