The Accessibility of Memory Items in Children's Working Memory

Hannah E. Roome (BSc, MSc)

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Psychology Department

Lancaster University

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Declaration

I declare that the thesis is my own work, and has not been submitted in substantially the same form for the award of a higher degree elsewhere.

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Abstract

This thesis investigates the processes and systems that support recall in working memory. In particular it seeks to apply ideas from the adult-based dual-memory framework (Unsworth & Engle, 2007b) that claims primary memory and secondary memory are independent contributors to working memory capacity. These two memory systems are described as domain-general processes that combine control of attention and basic memory abilities to retain information. The empirical contribution comprises five experiments that specify how adults and children access, manage and report memory representations held in working memory. They provide a developmental perspective of the characteristics of these cognitive constructs. This thesis has combined traditional measures of primary and secondary memory (free recall) and methods used to classify individuals recall into the two independent systems, with new convergent paradigms in order to identify developmental trajectories of memory performance. The findings point towards qualitative and quantitative differences between how adults and children focus their recall from working memory. Primary and secondary memory capacities increase across childhood, but they seemingly develop at different rates. Between the ages of five- to ten-years children are reliant on the active maintenance of memory items within immediate memory, as controlled search and retrieval processes were far more demanding on children's cognitive system. However, they did benefit from structured recall support and self-driven search processes, facilitating secondary memory. In addition, the experiments emphasised the impact of presentation modality on recall characteristics that are likely to be observed, and the susceptibility of information loss. Whilst auditory information reveals itself as highly accessible, it is also vulnerable to displacement and interference. In contrast visual representations appear to be more robust. Overall, the thesis will discuss the conceptual and empirical implications of whether the dual memory framework can help understand how working memory develops.

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Publications

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The findings of all experiments from chapters two to six have been presented at a variety of conferences as posters and/or oral presentations.

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Summary of the thesis

This thesis reports five experiments that specify how children and adults manage to report representations held in working memory. In particular, it draws on the adult-based framework that there may be two systems for retention: primary memory (PM) and secondary memory (SM). The experiments aimed to provide a developmental perspective of the characteristics of these cognitive constructs. Experiment 1 employed free recall tasks, a complex span task, as an index of working memory capacity (WMC), plus a new measure of focused recall and attentional management, the serial interleaved items task (SIIT) for children (aged five- to eight-years) and adults. Whilst children's free recall was largely recency-based, adults' performance was more likely to show additional primacy-based recall, reflective of an immediate output strategy compared to a balanced ability to recall immediate information as well as retrieve memory representations from a longer-term store. Additionally, the complex span measure correlated with the derived PM and SM estimates. Age-related increases in SIIT alongside improvements in attentional allocation were evident, which also correlated with WMC. Experiment 2 specifically focused on two modified versions of the SIIT task. Results suggested subtle changes in attentional management, and emphasised the ease at which auditory items were recalled, which in turn increased their susceptibility to interference in comparison to visual information.

Experiment 3 recruited children (aged five- to ten-years) and adults, focusing on a split- span task. Presentations lists were partitioned by presentation modality and recall was cued to prioritise initial recall to primacy or recency sections. Children still maintained their recency based recall strategy, and showed limited ability to retrieve memory items from the beginning of the list despite being instructed to recall specific sections. The accessibility of different types of memory representation did affect this. Whilst the auditory information was highly accessibly for immediate output, the visual representations appeared most robust and

less susceptible to decay and interference.

In order to further understand the developmental origins of the processes that underpin SM, Experiment 4 tested children (five- to ten-years) and adults using a cued complex span task, and a delayed cued recall task. When participants could not recall a target item, they were cued with either contextual sentence information or word cues specific to the target memory representation. Alongside age-related increases in the effectiveness of cues, the sentence cue generated greater recall across all age groups. Children found the delayed cued recall noticeably difficult, potentially explaining why children rely on recency-based recall strategies. Experiment 5 adopted an adult based conceptual span task in children (aged seven- to ten-years) to determine whether search and retrieval processes contributed to reading comprehension. Results suggested that individual differences in self-driven search processes were related to working memory and reading comprehension. However, children's vocabulary knowledge had a greater influence on comprehension compared to the working memory tasks.

The findings point to qualitative and quantitative differences between children and adults in how they focus on recall from working memory, and the benefits that can accrue from structured recall support and self-driven search processes. The experiments also emphasise that presentation modality affects the recall characteristics that are likely to be observed, and the susceptibility of information loss. The thesis will discuss the developmental trajectories of memory performance alongside individual differences in memory and school- based skills. The thesis will also discuss the conceptual and empirical potential of several new child-appropriate paradigms that are explored in this thesis.

Chapter 1

Literature review: the development of working memory capacity in children

Working memory is a dynamic cognitive system brought to the forefront of cognitive psychology by the work of Baddeley and Hitch (1974). While short-term memory is often described as the ability to store information over a short period of time, working memory is distinct from this conception. Whilst it converges with our understanding of short-term memory and the ability to store information, it holds an additional function; the ability to manipulate and integrate incoming information (Kane & Engle, 2002). An additional evolution from the unitary short-term storage models; working memory was described as a multi-component model (Baddeley, 1986; Baddeley & Hitch, 1974). Verbal-phonological and visuospatial representations are held in separate memory systems. Both types of information are then managed and manipulated by attentional related processes from the central executive (Cowan, 2008). At its core, working memory capacity (WMC) involves the management of to-be-remembered items on the one hand

and concurrent representations on the other. This has produced interest in inhibitory processes for the gating of information into the system, the housekeeping of information already there (Kane & Engle, 2002; Hasher et al., 2007) and the impact of representational overlap between memory items and processing items (Saito & Miyake, 2004). Working memory has been widely linked to a variety of higher-order cognition such as problem solving, reading, intelligence and planning (Unsworth et al., 2010). It is thus vital to understand the mechanisms involved within working memory, in order to examine the accessibility of memory representations within the cognitive system.

Over time there has been a shift in the definitions and descriptions of working memory. This reflects the success of the model and its breadth of scope, involving attentional processes plus short-term memory components. Researchers have placed different emphases on where individual differences in WMC lie: storage capacity, processing efficiency and the use of executive demands all involved in the classic conceptualisation of working memory (Jarrold & Towse, 2006). However, as a consequence of the different models focusing on different components, working memory has lost its familiarity as a model (Miyake & Shah, 1999). One of the main conceptual disagreements is whether working memory consists of a unitary system with a single pool of general purpose resources that can be used for a variety of cognitive processes across different domains or whether working memory is a more differentiated system with separate domain-specific resource pools.

Despite differences in the functioning of working memory as a cognitive system, the main task used to test WMC has remained the same: the complex span task. This specific task incorporates a processing element and a storage element, which are interleaved with each other. This is in line with the functional description that working memory enables the storage of a limited amount of items whilst processing a new mental activity (Conway et al., 2005). Thus, participants' performance on complex span tasks is an index of their WMC: the number of items they are able to recall whilst also processing new, incoming information. The experimental use of storage and processing within complex span tasks has remained the same since it's first use in 1980 (Daneman & Carpenter, 1980), but a variety of different stimuli have been used to measure storage (e.g. words, digits, dots in an array) and processing activities (e.g. true/false statements, sentence completion, arithmetic), as well as other manipulations within the task (e.g. Towse et al., 1998: time provided for processing; St Clair-Thompson, 2012: whether different lists lengths are presented sequentially or randomly). Therefore, the wide scope of experimental manipulations within complex span tasks has had a huge impact on how researchers measure working memory in adults and children and contributed to the different theoretical perspectives of what drives WMC.

The resource sharing hypothesis (Daneman & Carpenter, 1980) identified working memory as a unitary, undifferentiated, but limited resource pool that has to be shared between the processing and storage elements of the cognitive construct. In order to investigate the hypothesis, a specific complex span task called a reading span task was used. This task incorporated participants ability to read a series of unrelated sentences as the processing element of the task, and then recall the last word of each sentence in serial order, the storage component. Individual differences in WMC were attributed to the efficiency with which information is processed. As a limited capacity resource, those who are able to process information quickly have more resources available to store information. This is what defines WMC as part of this perspective. Case et al. (1982) followed a similar school of thought working with children, using a counting span task. The developmental increase in working memory span performance was explained by the processing speed with which children could count. In this case, the resources available to children remain constant, but the efficiency in which they can process information increases. The resource-sharing model has been the dominant description since the 1974 model (Miyake, 2001). However, alternative perspectives were proposed, contesting the validity of this particular model.

Towse et al. (1998a, 2000, 2002) claimed that time-based forgetting is an important factor when understanding complex span performance. Towse and colleagues proposed that individuals switch between the processing and storage elements as opposed to simultaneously, as described by Daneman and Carpenter (1980). In accordance with the resource sharing model, processing speed is a factor that contributes to working memory performance. However, increases in task difficulty are confounded by increases in temporal delay. This was shown by Towse et al. (1998a) who found performance on three types of complex span tasks (counting span, operation span and reading span tasks) were substantially reduced when the retention interval of memoranda was increased. However, the difference lay in the fact that the processing difficulty was equivalent across the trials. Towse et al. (1998a) suggested as much as processing speed is an important element in understanding working memory and its development, there is also a time-based forgetting component that needs to be considered. This directly corresponds with the time taken to complete the task, thus affecting the retention of memory items.

Whilst the previous models focused on the processing of information within the working memory system, Engle et al. (1999) directed their attention to the notion of controlled attention as the principal component of working memory. A similar architecture to the original Baddeley and Hitch (1974) model, it combined domain-general controlled attention with two domain-specific stores. However, its functioning was very different. Engle et al. (1999) defined working memory as a unitary system consisting of a store in the form of long-term memory traces active above threshold. The model proposed controlled attention, not memory, as the primary component of WMC. Thus, their definition of WMC considers individual differences in the ability for controlled and sustained attention in the face of distraction or interference, analogous with the central executive (Baddeley, 1986). It does not include individual differences in the storage of information (Engle et al., 1999). Domain-general control abilities are needed to actively maintain task relevant information in the presence of potential internal and external distraction. Therefore, working memory may be multifaceted, but it is attentional control that generates its predictive power.

Engle et al. (1999) introduced the notion of aptitudes and working memory as both being dependent on the ability to control attention. Unsworth and Engle (2007b) took it a step further and proposed the dual-memory framework that explains adults' WMC through the independent contributions of primary memory (PM) and secondary memory (SM). The alternative account is based upon the classic dual-store models that were proposed in the 1960s and 1970s (e.g. Atkinson & Shiffrin 1968; Shiffrin 1970; Waugh & Norman 1965), combined with controlled attention from the executive attention model of working memory. Therefore, neither WMC or the distinction between PM and SM are new concepts to the field, yet it has not been until recently that the two notions have been explicitly brought together. The application of PM and SM to a new account of WMC, encapsulates a different architecture in comparison to the original conceptualisation of working memory. The framework is more in line with models that evaluate the size of the focus of attention (Cowan, 2001) or the region of direct access (Oberauer, 2002). This is in contrast to models that rely on processing and storage activities, for example, the resource-sharing (Daneman & Carpenter, 1980) and task-switching accounts (Towse et al., 1998a) of working memory. The notion of a framework that combines two functionally distinct components that both independently contribute to WMC has the potential to provide an interesting, alternative account of the processes that underly the functional, but complex working memory system.

1.1 The use of dual-store models to explain working memory capacity (WMC)

There is a history of research investigating the theoretical concept of PM and SM, pioneered by the work of James (1890). PM was described as the psychological present, an event held in consciousness, but held over a fixed period of time, whilst SM is full of gaps and distortions, that must be retrieved from memory. Almost a century later, the first literature to propose a model of short-term memory that operationally distinguished PM and SM was carried out by Waugh and Norman (1965). The authors developed a mathematical model based on the assumption that long-term memory is used when trying to remember a list of items. However, at the point of recall, only the last list items remain in short-term memory. This model assumes that the serial positions within a presentation list are stored within two independent systems: short-term storage and long-term storage. Using an independent probability formula, Waugh and Norman (1965) predicted total recall by $R(\mathrm{i}) = P(\mathrm{i}) + S(\mathrm{i}) - P(\mathrm{i})S(\mathrm{i})$. $R(\mathrm{i})$ is the probability that item i will be recalled; $P(\mathrm{i})$ represents the probability that it is in PM; and $S(\mathrm{i})$ the probability that it is in SM. The probability of an item being in PM is calculated by $P(\mathrm{i}) = [R(\mathrm{i}) - S(\mathrm{i})]/[1-S(\mathrm{i})]$. In order to test the formula, free recall measures were used. This type of task facilitated the unloading of the last few items of a list straight away, whilst the recall of middle positions remains at asymptote. Consequently, this allows the estimation of $S(\mathrm{i})$ from the mean proportion of items recalled from the middle of a long list and estimation of $P(\mathrm{i})$ for each of the last seven items in the list.

Atkinson and Shiffrin (1968) proposed the dual-store model of memory, extending the work of Waugh and Norman (1965) and the conceptualisation of the structure and functioning of human memory (Richardson, 1996). Atkinson and Shiffrin's model contained three structural components of varying characteristics: (1) sensory register (2) short-term store and

(3) long-term store, all of which have access to control processes such as coding procedures, rehearsal operations and search strategies. Atkinson and Shiffrin (1968) proposed that information enters the sensory register, which is very susceptible to decay and the permanent loss of information. Nonetheless, a fixed proportion of information that is attended to is transferred and actively maintained in the short-term store for a short duration. As with Waugh and Norman's (1965) model, when faced with new, incoming information, the short-term store suffers from the displacement of memory items into the long-term store or permanent loss. This is dependent on the control processes in place, for example rehearsal mechanisms that enables the representation of items in both stores. At the time the original model was proposed, the authors did not consider the short-term store to have any special importance in how it may contribute to a wider range of tasks beyond learning and memory (Richardson, 1996). However in a more developed model, Atkinson and Shiffrin (1971) considered the short-term store as the working memory component of the model where decisions are made and information is directed. This is based on the assumption that the control processes are centred on the short-term store and act through it, receiving information from both the sensory register and the long-term store.

This was the original categorisation of items that are actively maintained in a limited capacity memory system and the effortful, strategic search and retrieval processes required for a longer-term, more durable memory store. The traditional view of human memory offers a simple explanation of how short-term memory is a gateway to a more permanent longer-term memory. However, this theory was predominantly descriptive and the memory model was moulded to fit the findings already obtained by free recall. The dual-store theories of memory represented the short-term store and the long-term store as a series of boxes. The boxes do not imply that memory is exclusively in one box or another. They are interpreted as the entry of information from a stimulus into one store and then the next (Cowan, 2008). Baddeley (2012,

2007) provided limitations regarding this argument. The dual-store models proposed that the retention of information in short-term memory was enough for information to be transferred to long-term memory. This implies that the longer information was held in the short-term store, it improved the likelihood of information being transferred. However, there were a series of studies that attempted to test this and were unsuccessful (e.g. Bjork & Whitten, 1974). It was revealed that the processing performed on information that had entered the system was more important than the duration of time that information had been held in the short-term store as assumed by Atkinson and Shiffrin (1968). Therefore, Baddeley and Hitch began their research by investigating the relationship between short-term memory and long-term memory, asking the question: what was the function of short-term memory if it was not a functional, working memory (Baddeley, 2007)?

There is little doubt that the model of working memory by Baddeley and Hitch (1974) has been the most influential model in regards to the retention of short-term information. While the model is an elaboration of the unitary short-term memory models (e.g. Atkinson & Shiffrin, 1968), Baddeley and Hitch (1974) argued against a unitary, limited capacity short-term store. Instead the short-term store was separated into two systems: the phonological loop and the visuospatial sketchpad. With this change in architecture, the emphasis shifted to active processing of information as opposed to the passive storage of information (Healy & McNamara, 1996). The phonological loop has received the most empirical support; the storage of information through the use of subvocal rehearsal. Without the use of such rehearsal, auditory information is susceptible to rapid decay. The visuospatial sketchpad has received less attention, but simply performs the same function as the phonological loop but for visual and/or spatial information. It serves a purpose of integrating spatial and visual information acquired from a variety of sources such as vision, long-term memory, language or touch (Baddeley, 2007).

More recently, Unsworth and Engle (2006a,b, 2007a,b) have re-visited the conceptual characteristics of PM and SM, originally introduced by Waugh and Norman (1965). As part of their rationale, the authors provided a functional description of Baddeley and Hitch's model as a cognitive system that provides control in order to overcome automatic tendencies, and provides the ability to simultaneously process and store information. Unsworth and Engle (2007b) described their view of working memory as "a subset of activated memory units, some of which are highly active and can be considered to be in a limited capacity short-term component." (p. 105). Within working memory, two key functions are necessary; the maintenance of new information in the presence of distractions that can be internal and external. The second is retrieval, as not all information can be actively maintained, and therefore task-relevant information needs to be retrieved.

Based on the original conceptualisation of the dual-store models by Atkinson and Shiffrin (1968) and Waugh and Norman (1965), PM and SM were proposed as independent contributors to adult WMC. PM requires the active maintenance of a fixed number of representations, whilst SM holds the duty of successful retrieval of items via a contextual, cue-dependent search process. The evolution of PM and SM to the current dual-memory framework has brought a shift in how they are conceptualised. As part of their name, the short-term and long-term stores were conceived as unitary memory stores. However, the notion of PM and SM as part of the WMC account does not follow suit. It should be acknowledged that the dual-memory framework is an outgrowth of the controlled attention view (Engle & Kane, 2004), and thus there are similarities between the two views, i.e. domain-general attentional resources (Chein et al., 2011). Therefore, the concepts of PM and SM are not synonymous with short-term and long-term memory respectively. Instead, the definitions focus on different underlying processes that are not tied by time scales (Hall et al., 2015; Jarrold et al., 2015). It is a combination of attentional control, activation maintenance, blocking interference and inhibiting distractions with basic memory abilities within immediate and long-term stores.

PM in the current dual-memory framework is described as a dynamic, flexible system adapting to the required task demands. Consistent with previous literature, PM can maintain approximately four items (e.g. Atkinson & Shiffrin, 1968; Cowan, 2001). However, keeping memory representations active in PM is dependent on the allocation of attention. If attention is removed from the active maintenance of a number of memory representations, items are displaced from PM, either into SM or are forgotten altogether. For example, when presented with a series of more than four items, the original PM items that were being maintained within the construct are displaced by new, incoming information and held in SM. Individual differences in PM use are attributed to the ability to actively maintain items in PM in the face of distraction. When individuals need to actively maintain items in PM, those with a low-WMC are more likely to have their attention captured by other elements in the environment, thus affecting not only PM use but also WMC. Individual differences in the control of attention is evident in tasks, such as dichotic listening tasks (Colflesh & Conway, 2007; Conway et al., 2001), which have been used alongside antisaccade (Kane et al. 2001), and stroop tasks (Kane & Engle, 2003) as support for the executive attention account of working memory. In these tasks individuals have to block distracting information in order to retain their target information. One example is using the "cocktail party" task (Cherry, 1953), individuals learn to repeat an auditory message out loud that is played to one ear, and ignore another message played into the other ear that intermittently includes the participant's name. Conway et al. (2001) showed individuals with high-WMC detected their name significantly less than individuals with low-WMC. This supports the ability to allocate attention effectively, and select target streams of information as a functioning requisite of WMC.

PM is conceptually similar to the focus of attention proposed by Cowan (2001). The focus of attention reflects what is currently in conscious awareness, a capacity that has demonstrated age-related and individual differences in capacity (Cowan, 2005; Cowan et al., 2006). Cowan's nested framework model stated that memory consists of items in the focus of attention, items activated in long-term memory, and items stored in inactive long-term memory. The process begins with sensory memory activating items from long-term memory or creating a new representation for new items, which move to the fringe of consciousness. If items are selected, then their representations are pulled into the focus of attention, which is the centre of consciousness. The focus of attention is capacity-limited, of approximately four separate units in adults, which develops through childhood (Cowan et al., 1999, 2005). Items can only be kept in the focus of attention through strategic processes, such as rehearsal. When the number of items in the focus exceeds an individual's capacity, or when attention is not maintained on the items, memory items leave the focus of attention to return to the activated portion of long-term memory.

In contrast to PM, SM is characterised as a longer-term, more durable memory system, reliant on controlled, cue-dependent search processes in order to retrieve memory items (e.g. Shiffrin 1970; Shiffrin & Atkinson 1969; Unsworth & Engle 2007b). Efficient use of SM requires individuals to use a range of internally generated contextual cues, which activates items held within a SM search set. The contextual cues are used to de-limit the search set, in order to retrieve target memory representations. At presentation, a memory item becomes associated with a range of contextual elements within a hierarchy. This ranges from slow, evolving, global contextual features, such as the room, to rapidly changing contextual cues associated with each item (Glenberg et al., 1980). At retrieval the different contextual elements can be used as cues to activate items associated with a given level of context. Individual differences within this cognitive construct are the ability to de-limit the search set and retrieve the target memory representations from SM. Adults with high-WMC are better at using cues to guide the search process (Unsworth, 2009; Unsworth & Engle, 2007b). They are able to generate more specific internally generated contextual cues that focus the search for the target memory representations and exclude irrelevant information. In comparison, low-WMC individuals use far noisier contextual cues, causing a poorer recall of information stored in SM (Unsworth, 2009).

The use of contextual elements from a longer-term store holds conceptual similarities with other models that have aimed to understand the underlying processes of working memory. The notion of a longer-term more durable memory system implies the use of long-term memory as a supplier of memory representations that need to be retrieved. Cowan et al. (2012) noted that long-term memory contributions have been observed in tasks considered to be sole measures of working memory. Therefore, WMC can be improved by other memory mechanisms, such as activated portions of long-term memory. Ericsson and Kintsch (1995) proposed the long-term working memory account, which relies on a stable retrieval structure, alongside cues used to indicate the type of information required to make it accessible in short-term working memory. The theoretical difference of this model compared to others (Daneman & Carpenter, 1980; Engle et al., 1999; Towse et al., 1998a) was the assumption that efficient retrieval from long-term memory contributed to performance on working memory spans as opposed to the notion that memory items are continuously actively maintained during performance on the same span tasks.

The accessibility of memory items in a long-term, more durable store requires sufficient contextual information to facilitate retrieval. From this point of view, Towse and colleagues introduced the recall reconstruction hypothesis tested in adults (Towse et al., 2008) and children (Towse et al., 2010). Cowan et al. (2003) performed response time analyses of children's performance on working memory span tasks. It was evident that pauses between item recall were longer in sentence-based span tasks, such as listening and reading span tasks. The recall of items was so very long it implied that participants were drawing on a different type of procedure in order to generate the memory item. This suggested participants were engaging in a search process from long-term memory. Towse et al. (2008b, 2010) provided direct evidence of reconstructive processes during recall in a reading span task. When the opportunity arises, individuals are able to revive memory representations on the basis that there is a cooperative relationship between the processing and storage of information (Towse et al., 2010). Therefore, participants are able to use sentence meaning or sentence words that have also been encoded in order to retrieve target information. Despite only investigating semantic associations, Towse and colleagues believed that the reconstruction process is more general and applies to other contextual information. The revival of a memory representation involves a spectrum of different coding cues, leading individuals to have a much richer set of representations than just the target task memoranda.

The conceptual argument of contextual information facilitating retrieval has led to investigations into the extent to which context can facilitate recall. Schroeder et al. (2012) gave participants either short stories as part of the processing elements of a reading span task, one continuous story, or a traditional reading span task. Contextually related sentence sets improved working memory performance in comparison to the traditional complex span task. However, this was lost when the entire processing component was one continuous story. This suggests the need for an element of uniqueness within the contextual cues used. This is analogous to the continuum of contextual cues described by Unsworth and Engle (2007b), and where the individual differences lie in SM retrieval. The more general the cues are, the probability of retrieving multiple memory representations associated with the general cue is increased. Thus, the presence of usable cues is not enough, the target information must be associated with specific, unique context to aid retrieval.

Overall, the dual-memory framework by Unsworth and Engle (2007b) and the combination of the cognitive concepts of PM and SM as an alternative account of WMC has provided a new means of investigating the underlying processes of working memory performance.

The authors highlight their own limitations of the framework, including being descriptive, potentially too simplistic (Unsworth & Engle, 2006b), and unable to account for phenomena such as word frequency, word length, rehearsal and phonological similarity. There are also alternative arguments that present a unified memory system that accounts memory task performance with a single set of principles and laws regardless of the testing circumstances (e.g. Brown et al., 2000). In spite of this though, Unsworth and Engle (2007b) argue that their framework of WMC is able to shed light on complex span task performance from an individual differences perspective, and its relation to higher-order cognition. The mechanisms that are described within the framework provide a combination of different types of processes necessary to access information retained within working memory. It provides an opportunity to look at the interaction of at least two different mechanisms. In this case the interaction between the retention of highly accessible information in immediate memory alongside the controlled search and retrieval processes for items that are retained, but outside of immediate view and therefore with reduced accessibility. The viability of the dual-memory framework in question then depends on whether the authors can prove that there is an advantage to recalling items before a fixed amount of time has passed or at least after the items are no longer attended to, and whether there is actually a mechanism with limited capacity that is able to hold information with new information only entering by the replacement of other information (Cowan, 2005).

1.2 Is working memory a mixture of domain-specific or domain-general components?

Within differing models of working memory there are divided opinions in regards to whether working memory is domain-general or domain-specific. There is potential that working memory as a cognitive construct requires both types of components. This leads to the question of whether working memory is reflective of a domain-general resource used for both processing and storage, or whether it is a reflection of multiple resource pools with domain-specific processing and storage functions (Bayliss et al., 2003). This is of interest because of the fact that the dual-memory framework does not provide any explanation regarding the domain-specificity of memoranda. The original dual-store models were defined as unitary stores, i.e. all information is stored in one place regardless of its modality. In addition, based on its extension of the controlled attention view, the allocation of attention and the controlled search processes are described as unitary domain-general resources. In fact, Chein et al. (2011) described the dual-memory framework as two dissociable domain-general mechanisms that contribute to WMC. Therefore, one needs to consider how this may be translated as part of a working memory model. Specifically, PM is analogous to a temporary memory system. Unsworth and Engle (2007b) provide a general description of PM, as an active cognitive system, which can maintain a limited number of memory representations over a short-period of time. However, there is no discussion of domain-specificity of the combined memory abilities. Therefore, when investigating its profile, it should be questioned as to whether it demonstrates any indications of domain-specificity, following the notions of the phonological loop and the visuospatial sketchpad. On the other hand, it may follow the traditional unitary store as described in the traditional dual-store models (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965).

This is clearly very different to the literature that have assessed working memory as a multi-component model. Bayliss et al. (2003) used four complex span tasks, crossing the verbal and visuospatial domains within the processing and storage components. Verbal and visuospatial processing efficiency and storage tasks were also used. The combination of all measures revealed themselves as a three-factor solution: two domain-specific storage factors and one domain-general processing factor. The findings described here cause theoretical concerns for the resource sharing account (Daneman & Carpenter, 1980) that assumes a trade-off between processing and storage components that compete for the limited resources. As the resource-sharing model is dependent on a single cognitive space, consequently it predicts working memory to be domain-general (Jarrold & Towse, 2006). Therefore, this account would not be able to explain any additional variance provided by domain-specific storage capacity. This is in contrast to Bayliss et al.'s findings that suggest processing speed and two separate storage capacities independently constrain performance on complex span tasks.

Engle et al. (1999) also argued against the resource-sharing model and the notion of processing efficiency as the intrinsic element of complex span performance. Instead, Engle et al. proposed the central executive is not only key, but also domain-general, with domain-specific storage components. Kane et al. (2004) presented adults with 12 working memory tasks that either involved the storage of verbal or spatial material. Their analysis suggested that these tasks were best modelled in terms of three factors, described above. Therefore, different aspects of working memory performance are supported by different, underlying structures, compatible with Baddeley (1986)'s model of working memory and poses a number of problems for a unitary resource-sharing model of working memory.

At the extreme, Shah and Miyake (1996) argued that two separate pools of domain-specific resources support the maintenance and processing of domain-specific information. This argument was supported by their findings that showed spatial span performance correlated with measures of spatial ability but not verbal ability. Similarly, verbal span performance correlated with measures of verbal ability but not spatial. Further, the concurrent processing demands of each task interfered with the maintenance of same-modality information more than different-modality information. Therefore, Shah and Miyake (1996) argued for two separate pools of domain-specific resources, which are necessary in order to process and maintain spatial and verbal information.

Altogether, the comparison of the different models of working memory, demonstrate the variability in how different aspects of working memory are supported by different, underlying structures (Jarrold & Towse, 2006). Each model described above displays differing extents to which working memory is defined as domain-general or domain-specific. At one extreme the processing and storage resources are both domain-specific (Shah & Miyake, 1996) to the notion of a domain-general executive resource and domain-specific storage systems (Bayliss et al., 2003; Kane et al., 2004). As a matter of course, the dual-memory model of working memory is still relatively new to the field, and therefore the extent to which the memory systems are domain-specific is still not fully understood. When described by Unsworth and Engle, it is acknowledged that the attentional control mechanisms within PM and SM are domain-general, fitting with the controlled attention view, but there is still a chance that the storage capacity could be domain-specific. However as far as the author of this thesis is aware, this has not been explicitly investigated.

A first line of enquiry that may question whether PM involves elements of domain-specific is the free recall literature and manipulations that affect the recency effect. The recency section of a serial position curve is susceptible to the modality effect, i.e. greater auditory recall in comparison to visual recall (Craik, 1969; Murdock & Walker, 1969; Watkins, 1972). In reference to the multi-component model or working memory by Baddeley and Hitch (1974), PM could follow the description of domain-specificity, in line with the phonological loop and the visuospatial sketchpad. However, the modality effect was explained in terms of sensory memory stores, and the persistence of memory representations in echoic memory. It was suggested that information from echoic memory is transferred to the short-term store, whilst the visual information is no longer available as there is no corresponding visual buffer (Craik, 1969).

Another avenue of investigation into the domain-specificity of the memory construct PM is to investigate whether auditory PM tasks are susceptible to effects normally associated with the phonological loop, but not the visuospatial sketchpad. PM is defined as the ability to actively maintain a limited number of memory representations in the face of distraction. With reference to the irrelevant speech effect, irrelevant spoken material disrupts immediate memory performance believed to be due to spoken material automatically entering the phonological store (Salamé & Baddeley, 1982). How does dual-memory framework explain this? As part of the domain-general attention control, does it just need to apply greater control to auditory memory representations in comparison to visual memory or are there domain-specific differences in the storage of immediate information. Such effects provide evidence of the domain-specificity of the memory systems, and it is an example of a phenomenon that the dual-memory framework is not detailed enough to explain.

In terms of the domain-specificity of SM, this is potentially less of a concern. Shiffrin and Atkinson (1969) proposed that the long-term store was a self-addressable memory. It is beyond the scope of this chapter to attempt to outline its functional architecture, but there is no doubt that it is highly complex. The modality of information stored is one of the differentiations made within the long-term store in terms of how memory representations are organised and located. But it is also accompanied by other relevant dimensions of organisation (Shiffrin & Atkinson, 1969). Therefore, the current work focuses on verbal memoranda and its semantic content.

The extent to which measures of PM and SM demonstrate themselves as domain-general resources will be investigated within this thesis. This will be investigated in terms of the accessibility of different types of memory representations (auditory vs. visual) and whether the cognitive constructs demonstrate any differences of how target memoranda is maintained and retrieved, whilst being governed by the control of attention (the allocation of attention and search and retrieval processes). This will provide a wider understanding of how the model converges with the unitary, single pool resource models in comparison to the more differentiated, domains.

1.3 How to measure primary memory (PM) and secondary memory (SM)

The dual-store models (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965) and the more current dual-memory framework (Unsworth & Engle, 2007b) used free recall as a means of investigating the two independent cognitive constructs. Free recall is an episodic memory task whereby participants are presented with a list of items one at a time. Immediately after the presentation of the to-be-remembered items, participants have to recall as many of the items as they can in any order they wish (Bhatarah et al., 2006). A widely acknowledged phenomenon is participants' ability to successfully recall the beginning and end portions of a presented list in comparison to the middle items. These effects were named primacy and recency effects respectively, portrayed in a U-shaped serial position curve of recall. The dual-store models provided the simple, fitting explanation that the primacy effect reflected the use of the long-term store or SM, illustrated by a decline in recall from the beginning to the end of a list. In comparison, the recency effect demonstrated a rising accuracy from the beginning to the end of a list reflective of the output of items from the short-term store or PM. The underpinnings of free recall and the serial position curve have been paramount in the conceptualisation of dual-store models and the current dual-memory framework (Unsworth et al., 2011). The shape of the curve and observed serial position effects reflect the use of two separate stores (Atkinson & Shiffrin, 1968; Glanzer & Cunitz, 1966; Waugh & Norman, 1965). Despite other models of memory providing explanations of primacy and recency effects in free recall, the dual-component model is generally accepted as the explanation for this reputable finding.

As part of understanding the dissociation of the short-term and long-term stores, or PM and SM respectively, experimental manipulations have been implemented to provide evidence of two cognitive systems, dissociable from each other, contributing to individual differences in the ability to demonstrate active maintenance and long-term retrieval within a free recall task (Unsworth & Engle, 2007b). The primacy section of a list is more susceptible to manipulations of presentation rate (Glanzer & Cunitz, 1966), list length (Postman & Phillips, 1965; Tulving & Colotla, 1970) an items' frequency of occurrence (Raymond, 1969), phonological similarity (Craik & Levy, 1970), and semantic association (Craik & Levy, 1970). The recency section on the other hand remains relatively invariant to these types of manipulations, but vulnerable to the use of a distractor task between presentation and recall (Watkins, 1977), plus the modality of item presentation (auditory vs. visual: Craik, 1969; Murdock & Walker, 1969; Watkins, 1972). The dissociation found between experimental manipulations provides a wider understanding of the characteristics that surround the primacy and recency effects. For example, the use of an extended presentation rate provides participants' with the opportunity to use maintenance strategies such as rehearsal. Within the context of the dual-store model, information in the short-term store is lost unless maintenance strategies are enforced. Therefore, at a slower rate, information is maintained within the short-term store for as long as the individual desires it to stay there. Whilst information remains being rehearsed, items are transferred to the long-term store, which is a more permanent system. As mentioned previously, the dual-memory framework has not provided any explanation of the dissociations within the new conceptualisation of PM and SM. However, they have used it as supporting evidence of the constructs functioning independently of each other.

A separate avenue of research was the production of techniques that separated and measured the memory stores individually and empirically, alongside the emergence of the dual-store models. In order to determine empirical estimates of PM and SM, Tulving and Colotla (1970) created a method based on Waugh and Norman (1965) that differentiated between whether information was retrieved from PM or SM on free recall tasks. Using a tally system, an intratrial retention interval (ITRI) was calculated for each recalled item in regards to the number of words between a given word's presentation and recall. As part of the method, Tulving and Colotla (1970) stated that a recalled item with an ITRI of seven or below was classified as PM, whilst a recalled item with an ITRI score of eight or above, was classified as SM. Examining PM and SM as independent memory systems, confirmed that mean recall from PM was relatively invariant to independent variables such as list length and presentation rate. SM on the other hand was susceptible to list length and presentation rate, with overall increased performances for the slower presentation rate across three increasing list lengths. This technique provided an extension to the original Waugh and Norman (1965) method as it was not only accomplished in providing estimates of the number of items recalled from the two distinct memory systems, but it also identified which items were recalled from PM or SM (Watkins, 1974).

The description of theories, methods and evidence demonstrates the first developments of the characterisation of PM and SM. Watkins (1974) provided a review of selected theories and methods used to measure PM, including PM as a distinct storage system (Waugh & Norman, 1965); as a reflection of consciousness (Craik & Lockhart, 1972); and a limited-capacity retrieval process (Tulving & Patterson, 1968). In order to examine the effectiveness of the methods presented in this paper and their ability to distinguish different recall components with different properties, Watkins (1974) used empirical data taken from Tulving and Colotla's experiment to compare four different methods: (1) Waugh and Norman (1965); (2) Waugh and Norman, (1965 modified); (3) Tulving and Patterson (1968); and 4) Tulving and Colotla (1970). The aim of this was to investigate the variance of PM estimates from the four different methods. PM has a limited but constant capacity, reflected in the recency effect remaining constant despite experimental manipulations. Based on this notion, variance should be low for estimates of PM. The results demonstrated that the PM estimate variance for each technique was far greater for Waugh and Norman's (1965) methods followed by Tulving and Patterson (1968) and lastly Tulving and Colotla (1970).

Secondly, an analysis of variance using calculated SM to PM ratios for each measurement technique was carried out. Watkins (1974) believed that the ratio of the SM component to the PM component should correlate with experimental variables that affect overall recall. On this basis, an efficient method will generate a higher correlation. Once again this showed both of Waugh and Norman's methods to provide very low F-ratios, interpreted as an inefficient measure of PM estimate, whilst Tulving and Colotla's method provided the most reliable estimates for PM and SM. However, Watkins (1974) did not allow the preferred method to go without criticism. Watkins (1974) argued that a recency effect can span more or less than four serial positions and not all supposedly recency items are unloaded from PM. These two effects combined may in turn cause an under- or overestimation of PM capacity. Thus, this method cannot be used without acknowledging the methodological risks. This is an important point and will be returned to, not only in the current chapter, but as a discussion point in the empirical chapters.

The method provided by Tulving and Colotla (1970) is still used to the present day and has been validated in the adult literature (e.g. Craik, 1971; Unsworth & Engle, 2007; Unsworth et al., 2010). Further, studies from the adult literature have used this method to differentiate the two memory systems and their relation to fluid intelligence (Mogle et al., 2008; Shelton et al., 2010; Shipstead et al., 2014), individual differences in WMC (Unsworth & Engle, 2007b) and working memory training in adolescents and adults (Gibson et al., 2011, 2012, 2013). One may question the flexibility of the critical value seven to fit the capacity of PM in the participant sample tested, as criticised by Watkins (1974). In order to improve the reliability of the method, the critical value needs to be modified based on an independent measure of participants PM capacity (Jarrold et al., 2015). The only known paper to alter the critical value was Craik and Levy (1970), who modified the methods and lowered the critical number to six. This was based on a guessing correction technique used by Waugh and Norman (1965). The remaining literature has put faith in the threshold, which does provide direct comparison across findings, but it creates caution in regards to whether it is a reliable score of PM and SM estimates.

This section has provided the history and evolution of how PM and SM have been adapted as key contributors to WMC, and where it fits within the working memory literature. However, it is all based predominantly within the adult literature. Historically, the dual store models have focused on how adults use PM and SM and its relation to WMC. Very little work has been carried out to ascertain the developmental use of these two memory systems in children.

1.4 How do the dual-store models apply to WMC across the life span?

All the working memory models presented in the previous sections are predominantly based within the adult literature, suggesting that the functional architecture of working memory does not actually change across development (Alloway et al., 2006; Gathercole et al., 2004; Swanson, 2008). However, there is still a great deal that is not known about the underlying processes driving developmental differences in working memory. Turning to the theoretical development of PM and SM, developmental studies involving children have not been incorporated into the theoretical understanding of differences in how the underlying processes contribute to WMC across the lifespan.

Very few researchers have ventured into investigating the development of PM and

SM, let alone its relation to developing WMC. Following the free recall methods used to provide evidence for the dual-store models, Cole et al. (1971) and Thurm and Glanzer (1971) analysed primacy and recency effects produced by children in free recall tasks. Two different free recall paradigms were used: Cole et al. used 20-item lists, whilst Thurm and Glanzer used incremental lists lengths of two- to seven-items. Different age ranges were also used, with the former focusing on older children aged eight- to nine-years old compared to 11- to 12-years old; the latter comparing younger children aged five- to six-year olds. Despite this, both demonstrated that whilst the recency effect did not change as a function of age, the accuracy and size of the primacy effect increased by the same variable.

In comparison, Cuvo (1974) compared the serial position effects of ten- to 11-year olds, 13- to 14-year olds and adults on 20-item word lists. Developmental differences in the use of short-term and long-term stores were evident. Recall performance on recency items was similar for the two groups of children, but superior recency recall was evident in adults. In comparison, age-related increases in the recall of prerecency items were also found. The recency differences between the age groups led the authors to suggest that adults are better at unloading all items from the short-term store, in contrast to Cole et al. (1971) who used the same list lengths. However, an alternative explanation could also be a short-term store capacity difference between children and adults. Despite the children data not differing from each other, their PM capacity still had to increase to an adult level. An additional correlational analysis suggested the impact of rehearsal mechanisms increasing in the primacy effect, thus older participants were able to transfer items from the short-term to long-term store.

To provide a lifespan perspective, Foos et al. (1987) studied PM and SM estimates of children aged eight- to 12-years, compared with adults aged 20- to 32-years old and 60- to 79-years old. Using 15-item lists, PM and SM was categorised using the methods by Tulving and Patterson (1968). Therefore, the mean number of items recalled from the last four items in the list as an estimate of PM capacity, whilst SM estimates was the mean number of items recalled from the first 11 serial positions. The results showed both children and older adults produced lower PM scores than younger adults', however, older adults' produced lower SM scores than children and younger adults.

Foos et al. (1987) also used Watkin's (1974) modified version of Waugh and Norman's (1965) technique. PM was measured by using the proportion recalled on the last serial position multiplied by seven. SM was calculated by the average proportion recalled on serial positions four to eleven multiplied by 15. Within this method it showed children and older adults had a lower usage of PM than young adults. Older adults also had lower SM use than children and young adults. This led the authors to suggest that further research was necessary to determine the age at which children can use PM and SM at an equivalent level to adults.

Only one paper has assessed PM and SM in children as part of the dual-memory framework. De Alwis et al. (2009) tested children aged six- to 16-years old on free recall and fluid intelligence. In a list of 14 items, the first ten items are recalled from SM and the final four items are unloaded from PM, similar to Tulving and Patterson (1968). Their data showed an age-related increase in the primacy effect, which they attributed to an age-related increase in SM use, but no such effect on PM. This has sparked interest in the statement made by De Alwis et al. (2009) that "children's secondary memory improves with age, whereas their primary memory does not" (p.929).

The statement made by De Alwis et al. (2009) has been contested by Hall et al. (2015) and Jarrold et al. (2015) who have taken a specific interest in how PM develops. Both authors were surprised by the notion that PM does not increase through childhood considering the evidence provided by others investigating the increase in the size of the focus of attention across children of different ages (e.g. Cowan et al., 2005). In order to investigate this further, Jarrold et al. (2015) used free recall measures to analyse the serial position effects produced by children aged five- to eight-years old. Jarrold et al. (2015) tested the validity of De Alwis et al.'s classification methods by gathering their own children's dataset and implementing the method used by De Alwis et al. (2009) on nine-item lists. This replicated De Alwis et al.'s findings; age-related increases in the beginning three, and middle three serial positions, but not the last three serial positions. However, this was put into contention when individual's order of report was controlled for. Jarrold et al.'s new, more sensitive analysis demonstrated developmental increases in PM capacity.

As demonstrated above, the field has largely focused on understanding developmental differences in immediate memory capacity. In comparison, little investigation has been carried out in regards to the development of retrieval from SM. An example of a paper that has put a greater focus on SM was by Gibson et al. (2010). The two memory systems were analysed in adolescents with developmental disorders to show deficiencies in SM. Gibson et al. (2010) investigated whether the associated working memory deficit in children with attention deficit/hyperactivity disorder (ADHD) was attributed to PM and/or SM deficiencies. The active maintenance of items in PM seemed to remain intact in comparison to typically developing controls. However, the retrieval of memory representations from SM was significantly lower in the ADHD participants, attributed to a SM deficit. The authors questioned why this deficit occurred, following the line of thought that the search set within SM included too much irrelevant information, thus causing individuals with ADHD to retrieve more intrusions. This suggestion fits with individual differences in adults' retrieval abilities from SM and its subsequent contribution to WMC (Unsworth, 2009). SM was found to drive complex span performance; therefore, if adolescents with ADHD are producing a SM deficit, it provides the simple suggestion that individual differences in SM use is a key contributor to WMC.

The methods used to distinguish between PM and SM need to be considered when evaluating the applicability of the dual-memory framework as an account of the development of WMC. There have been issues in how serial position effects have been analysed to determine primacy and recency effects, and the application of adults' categorisation methods to children's data. Within the work by Cole et al. (1971) and Thurm and Glanzer (1971), the recency effects were considered to only include the last serial position (Dempster & Rohwer, 1983). Therefore, it is not surprising that children did not differ in the recall of recency items. It is speculated that children should be able to recall the final list item, as it is the last item to be presented, and thus should be the most accessible item for them in a free recall context. De Alwis et al. (2009) divided their 14-item lists into three sections: the first four, middle six and final four items. The final four was a reflection of an adult PM capacity, as stated by Unsworth and Engle (2007b). Testing six- to 16-year olds is a large age range, and it is debatable whether using an adult PM capacity as a marker of PM use in children as young as six is reliable. This is of course dependent though on the theoretical perspective taken by the authors.

The method by Tulving and Colotla (1970) has not yet been applied to children, thus it is hard to state whether it would or would not show PM as a construct that develops in capacity through childhood. An immediate concern in its application to children is the critical value seven and its basis on the 'magic number seven' (Miller, 1956). Craik and Levy (1970) stated that the choice of seven was based on a recency effect of six- to seven-items. However, unlike traditional measures of the magical number, such as digit span, the method rarely produces PM scores of three- to four-items (Shipstead et al., 2014). Based on this, it is not clear whether this method can be applied to children who potentially have reduced memory capacity overall (Jarrold et al., 2015). Gibson et al. (2013) expressed concern regarding this method when working with adolescents. The method uses a rigid criteria for defining PM and SM, which may not be optimal for measuring change in these components. One must be cautious that this method does not overestimate or underestimate the number of items recalled from each system. One would thus immediately question this justification when applying it to children. If PM capacity is small and does develop through childhood, the method will not truly capture the capacity of either system; PM will be overestimated and SM will be underestimated.

The ages of the children used to test PM and SM also needs to be considered. Cole et al. (1971); Cuvo (1974) and Foos et al. (1987) used older children, with the latter two articles comparing performance with adults. It was those two articles that showed no difference between children groups, but they still recalled fewer PM items than adults. De Alwis et al. (2009) tested children aged six- to 16-years of age, who might be expected to show a more adult pattern of performance. Therefore, one could argue that the rate of development reduces at the point at which children begin to use rehearsal and SM becomes more accessible to use. Examining the performance of younger children before, during and after the emergence of rehearsal may provide greater insight into whether the ability to actively maintain items in PM does increase as a function of age.

The examination of the dual-memory framework from a developmental perspective needs to address issues that have materialised from the historical literature. Firstly, as part of understanding the development of the individual cognitive systems, the literature has focused on their capacities. This has provided an underlying tone that PM and SM are memory stores, following the more traditional dual-store models; with fixed, static capacities. There is no consideration in the historical work of the underlying domain-general processes that may influence capacity. With the renaissance of PM and SM as cognitive contributions to WMC, Hall et al. (2015) and Jarrold et al. (2015) have followed the more current argument of the combination of controlled attention and basic memory ability. Jarrold et al. (2015) has focused on whether partitioning children's free recall performance in PM and SM components are valid, and its implications for the theoretical interpretation of the development of PM capacity. Hall et al. (2015) also combined methodological and theoretical implications in the measurement of PM capacity. Using three different paradigms (free recall task, serial interleaved lists task and split span task), the authors tested whether children's performance on the novel measures can capture the cognitive characteristics of PM and whether they can predict contributions to working memory tasks and academic achievement. In contrast, there has not been any published investigation into how younger children use SM. Therefore, the developmental changes in the ability to carry out contextual, cue-dependent search processes away from the estimates generated is unknown.

It is at this point that the current thesis begins. To carry on the work of Hall et al. (2015) and Jarrold et al. (2015), the two memory systems will be examined, not only when they both have to contribute to a task (e.g. free recall), but also tasks that require the use of just one of the constructs. This will enable the investigation into the individual developmental trajectories of PM and SM, and whether they occur at different rates. Within PM, the use of traditional free recall and novel paradigms needs to investigate whether the current thesis can converge with the findings of Hall et al. (2015) and Jarrold et al. (2015) in regards to the increase in PM capacity in five- to eight-year olds. As part of explaining this phenomenon, the underlying processes that characterise PM need to be investigated, i.e. children's developing ability to allocate attention. It is already established that SM use increases across childhood. However, what now needs to be considered is how the search and retrieval processes that underlie this system develop as part of the explanation of WMC. By following these lines of investigation it will provide evidence of the combination of basic memory abilities and the control of attention, as set out by the researchers of the dual-memory framework.

1.5 Objectives of the thesis

WMC is an important construct within cognitive development, yet the basis of children's performance is not fully understood. The dual-memory framework provides an opportunity to apply a new account of how working memory develops through childhood, investigating how the processes that underlie PM and SM develop. By providing an account of developmental change allows exploration into the functional significance of the two different cognitive components. Specifically, it provides the potential for two new mechanisms to be explored as mediating factors in the development of WMC.

This thesis addresses the value of the historical concepts of PM and SM, their influence on current theories and how they influence the characterisation of children's working memory. Moving away from the temporal emphasis of short-term memory and long-term memory, the concepts of PM and SM provide insight into the processes that underlie the retention of memory representations (Hall et al., 2015). The proposal of the dual-memory framework that encapsulates PM and SM as individual contributors to adult WMC (Unsworth & Engle, 2007b) has provided an intriguing, alternative account of the cognitive processes that underlie WMC: the active maintenance of a fixed number of memory representations in PM and the strategy search and retrieval process from SM. Despite the framework's success as an alternative account of WMC, little research has extended the conceptual constructs as an account of the development of WMC in children. Therefore, this thesis aims to provide a developmental perspective of PM and SM in children aged five- to ten-years old and whether age-related differences in WMC are driven by changes in the capacity or the efficiency with which information is maintained and retrieved. In order to provide a complete examination of the developmental trajectory of PM and SM and their contributions to WMC, the investigation also included the evaluation of adult performance.

The first point of investigation in Chapter 2 was the use of free recall as a measure of PM and SM in adults and children. This provided the opportunity to explore age-related and individual differences in the reaction to traditional manipulations of free recall in the same way as reported in the adult literature. Alongside this, the free recall tasks examined the developing capacities of PM and SM using a method introduced in the adult literature by Tulving and Colotla (1970). Using this method, the estimates of the independent memory systems were used to determine the extent to which they predict WMC. This was carried out to determine age-related differences in the extent to which WMC is driven by the two independent memory systems.

In combination with the free recall paradigms outlined above, novel tasks were developed to isolate the memory systems and investigate their developing cognitive profile through childhood. In Chapters 2 and 3, the serial interleaved items task (SIIT) was adopted to further examine the underlying processes that conceptualise PM. The SIIT was based on dichotic listening tasks, modified to make appropriate for children aged five- to eight-years old. PM is highly dependent on the allocation of attention. In order to understand this cognitive construct it is important to not only observe its increasing capacity, but also ascertain how attentional processes develop and how they may contribute to the active maintenance of items in a capacity limited system. This particular task also extends our understanding of PM by introducing different presentation modalities to ascertain whether the modality effect was evident in adults and children as the literature would suggest it should be. This potentially could cause theoretical implications to the domain-generality of this specific system.

The accessibility of items in working memory is crucial to understanding its increasing capacity into adulthood. Not all information can be actively maintained in an immediate memory system, so children have to develop controlled search processes to access and retrieve information. Therefore, in Chapter 4, a second type of free recall measure was administered called the probed split span task. Through the use of recall probes and different presentation modalities, it provided another method to explore how adults and children use the two memory systems, and how the representation of memory items affects their accessibility in working memory.

To further understand how adults and children access, search and retrieve information from SM, three tasks were developed. In Chapters 5 and 6 the cued listening span task, delayed cued recall task and the conceptual span task continued to provide novel and more sensitive measures of the processes underlying the construct. As a final line of investigation, children's SM performance was related to their reading comprehension, to determine how the retrieval of SM items contributes to their understanding of text.

In summary, the experiments carried out produced PM and SM estimates in children, examined their contribution to developing WMC and measured the development of underlying processes required for the efficient running of the cognitive constructs. This determined whether the dual-memory framework should be considered as a new approach to understanding how WMC develops through childhood.

Chapter 2

The characterisation of primary memory and secondary memory in adults and children

2.1 Experiment 1: Introduction

Free recall is the most commonly used method to derive estimates of PM and SM as part of the historical dual-store models (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965) and the more current dual-memory framework (Unsworth & Engle, 2007b). This is an episodic memory task whereby participants are presented with a series of items that they can recall in any order (Bhatarah et al., 2006). Investigation into these cognitive constructs has mainly remained within the adult literature (e.g. Glanzer & Cunitz, 1996; Unsworth & Engle, 2007b; Unsworth et al., 2011; Unsworth et al., 2010; Waugh & Norman, 1965). The children's literature using free recall is relatively scarce in comparison. In order to investigate the development of PM and SM it seemed intuitive to start the investigation with the traditional measures that are still used in the more recent literature. Accordingly, the use of free recall paradigms can help establish whether the acknowledged change in working memory in childhood (Case et al., 1982) is accompanied by developmental increases in PM capacity, SM capacity, or both. In addition to this, a novel task was introduced, called the serial interleaved items task (SIIT) to address the conclusions made from the historical (Cole et al., 1971; Jablonski, 1974; Thurm & Glanzer, 1971) and current (De Alwis et al., 2009) findings that PM capacity is invariant to age. Taking into consideration the combined ability to allocate attention to the targeted memory items in the face of distraction (Unsworth & Engle, 2007b), with basic memory abilities, this particular task was used to investigate how attentional abilities may contribute to the retention and maintenance of memory items, impacting their accessibility in immediate memory.

Section 1.4 described the published literature that has investigated the development of PM and SM. There has been variation in the extent to which PM and SM increases across childhood. Using serial position effects and different categorisation methods (see section 1.3) there are those who have demonstrated age-related increases in SM but not in PM (Cole et al., 1971; De Alwis et al., 2009; Thurm & Glanzer, 1971). In the middle, Cuvo (1974) and Foos et al. (1987) reported that children of different ages did not differ in PM capacity but it was smaller than adults' capacity. However, more recently, Hall et al. (2015) and Jarrold et al. (2015) have shown than PM capacity does increase through childhood. The current experiment continues to work on the development of PM and SM. In conjunction with Jarrold and colleagues, the experimenter believes that the capacity of both constructs increases as a function of age. This is based on the notion that PM is synonymous with short-term memory (Baddeley, 1986), which demonstrates developmental increments in capacity across childhood (Dempster, 1981; Gathercole, 1999). In addition to this, PM has been compared to the focus of attention (Cowan, 2001), which increases in size throughout childhood (e.g. Cowan, 2005a).

The descriptions regarding adults' and children's free recall performance and their application to the dual-store models have been criticised for its use of aggregate performances and over-simplistic explanations. Unsworth et al. (2011) investigated inter- and intra-individual variation in adults' free recall to show individual differences in serial position recall strategies. Three recall subgroups were established based on participants' individual serial position functions: those who mainly recalled primacy items, recency items or both sets of items. Depending on their recall strategy, participants showed stronger primacy effects, recency effects or a balanced level of recall across all serial positions respectively. Therefore, different recall initiation strategies demonstrated systematic differences in recall profiles, very different to the traditional work (e.g. Glanzer & Cunitz, 1966; Waugh & Norman, 1965) that provided the simple description of the unloading of information from a short-term store, followed by retrieval from a long-term store. The literature testing children's free recall performance is also susceptible to the same criticism (Cole et al., 1971; Thurm & Glanzer, 1971). More recently, Hall et al. (2015) and Jarrold et al. (2015) found children aged five- to eight-years showed a propensity to begin recall with the last item, but a proportion of recalled trials began with the first list item. Therefore, critiques argue that aggregate serial position curves frequently used within the literature mask any differences in serial position functions between individuals. To accommodate this criticism, Unsworth et al's (2011) method was administered to the data collected from the adults and children on the free recall task. This will inform our understanding of individual differences in where children focus their recall strategy within each age group as well as across the lifespan.

Historically, PM and SM estimates were categorised by the method proposed by Tulving and Colotla (1970) that uses ITRIs and a critical value seven, described in section 1.3. Issues surrounding the rigidity of the critical value means that it may not be appropriate for children (Gibson et al., 2013), as it is not clear whether this method can be applied to children who potentially have reduced memory capacity overall (Jarrold et al., 2015). If PM capacity develops through childhood the method will not truly capture the capacity of either system; PM will be overestimated and SM will be underestimated. The method by Tulving and Colotla (1970) also assumes that individuals have to begin their recall from the recency section of the list. As previously mentioned, free recall tasks carried out by adults (Unsworth et al., 2011) and children (Hall et al., 2015; Jarrold et al., 2015) have shown individual differences in where participants begin their recall. Therefore, variation in the recall order affects the recall lags in ways that may not always map straightforwardly onto partitions of memory. The current experiment applied Tulving and Colotla's method to adults' and children's free recall performance to ascertain whether it provides developing increases in both PM and SM capacities. In addition, Jarrold et al.'s suggestion of lowering the critical value to accommodate children's smaller memory capacity has been applied to the current dataset. Therefore, the comparison of data using the critical values seven, four and two was administered to determine the extent to which that changes the profile of PM and SM estimates through childhood.

One potential reason for the differences within the children free recall literature is the variation in free recall task designs. The studies have used a variety of list lengths (Cole et al., 1971: 20-items; De Alwis et al., 2009: 14-items; Hall et al., 2015: two- to seven-items; Jarrold et al., 2015: nine-items; Thurm & Glanzer, 1971: two- to seven-items), and presentation rates (Cole et al., 1971: 2 seconds(s); De Alwis et al., 2009: 1s; Hall et al., 2015: 1s; Jarrold et al., 2015: 1s; Thurm & Glanzer, 1971: 1.5s), both of which affect the recall of primacy items (Brodie & Murdock, 1977; Glanzer & Cunitz, 1966; Murdock, 1962; Postman & Phillips, 1965; Tan & Ward, 2000; Tulving & Colotla, 1970). Within the adult literature, increases in list lengths reduces the recall of primacy items (Murdock, 1962; Ward, 2002). Children's reaction to this specific manipulation is also present. Hall et al. (2015) and Thurm and Glanzer (1971) demonstrated that as list length increased from two- to seven-items, the probability of recalling the primacy items decreased in children aged five-to eight-years. Whilst the increase in presentation rate increases the primacy effect in adults (Brodie & Murdock, 1977; Glanzer & Cunitz, 1966; Rundus, 1971), children do not react in the same manner. Murray and Roberts (1968) found seven-year olds did not show any difference between rates of 1s and 2s, whilst ten-year olds produced increased recall at the slower rate (Murray & Roberts, 1968). Adults in contrast show systematic increases in free recall when presentation rate is increased (Murdock, 1962). Therefore, one needs to consider how arbitrary choices of list length and presentation rate will affect the results collected, and the subsequent interpretation.

The reason for such a focus on understanding the developing capacities of PM and SM is due to determining whether these cognitive constructs contribute to WMC. This is part of understanding whether the dual-memory framework can be applied as an account to understand how WMC develops in children. WMC is indexed as span performance on a complex span task, a more traditional measure of working memory. Unsworth and Engle (2007b) used Tulving and Colotla's method to classify adult's recall into the two memory systems to find they independently contributed to WMC. Firstly, Unsworth et al. (2010) showed free recall, signified as a storage only task, measured processes largely similar to those for complex span tasks. In addition, structural equation modelling showed both PM and SM components derived from free recall accounted for unique variance in WMC, but were not correlated with each other (Unsworth et al., 2010). This confirmed the findings of Engle et al. (1999) who showed free recall measures to load as highly as complex span tasks onto WMC. Despite its growing prevalence in the adult literature, no one has investigated the developmental utility of PM and SM, as distinguished by Tulving and Colotla's method, and their relation to the development of WMC. The children literature that has measured PM and SM have shown relations between SM and fluid intelligence (De Alwis et al., 2009); a deficit in SM estimates in adolescents with ADHD in comparison to typical controls (Gibson et al., 2010); plus how novel measures of

PM capacity, including free recall contributed to complex span tasks (Hall et al., 2015). To the author's knowledge, there is no literature that has directly assessed children's PM and SM use as contributors to the development of WMC. Therefore, taking the PM and SM estimates derived from participants' performance, correlational analyses will inform the developmental perspective of whether children show independent contributions of PM and SM to explain WMC.

2.1.1 Does primary memory capacity increase over childhood?

In order to help resolve the theoretical issue of whether PM capacity does increase with age away from the limitations of the categorisation methods used in free recall, a complimentary paradigm was developed. The serial interleaved items task (SIIT) was based on dichotic listening paradigms that have previously been noted as a measure of adults PM capacity (Broadbent, 1958; Martin, 1978; Parkinson, 1974). Participants experience different auditory stimuli to each ear but are instructed to only pay attention to one of the sources. At recall, participants are instructed to recall both the attended and unattended information. Specific interest was held for the findings by Bryden (1971) who showed when participants recalled unattended items first, followed by attended items, the attended items suffered from a drop in recall accuracy. Bryden (1971) does not use memory as an explanation as that was not the focus of the work. However, an alternative interpretation could be proposed from PM. Participants were able to maintain the attended four items and unload them at the point of recall. However, when attention was diverted to the unattended items, the probability of recalling the attended items diminished as a consequence of displacement by the unattended items.

The dichotic listening task used by Bryden (1971) was adapted by Hall et al. (2015) and the current experiment in order to make it appropriate for children aged five- to eight-years. The developmental implementation of this task alternated the presentation of the two streams of information. The two types of presentation sources were labeled focal and nonfocal items. The terms were chosen as they do not generate any form of implication in regards to the attentional processes used, they just refer to the experimenter-assigned priorities. Hall et al. (2015) analysed a highly similar version of the SIIT (entitled the serial interleaved lists task. The current procedure involves an additional constraint of serial order requirements), arguing that performance provides several signatures indicative of PM.

To try and capture this characterisation of PM processes, for 80% of trials participants were instructed to recall focal items in serial order, whilst for the remaining 20% of trials, participants were instructed to recall nonfocal information. PM should retain the focal memory items. However, there is a possibility that SM may be required in the recall of low priority nonfocal information, especially for longer list lengths. The interleaved nature of the task may cause the displacement of PM items into SM. Martin (1978) suggested that the use of a longer-term store was necessary in the recall of unattended information within dichotic listening tasks. However, others would argue that unattended items were recalled from a separate perceptual memory system (Broadbent, 1958; Bryden, 1971). Therefore, by analysing the inter-relations between nonfocal recall and listening span and free recall, it can shed light on whether SM contributes to performance on this type of task.

The SIIT provided the opportunity to examine the underlying mechanisms that also need to develop in order to ensure optimal use of PM capacity. As previously described PM is dependent on the allocation of attention. Therefore, the ability to maintain attention on relevant information and prevent attentional capture from elsewhere is crucial to age-related and individual differences in PM use. The developmental literature has shown older children to be better at selecting target memory items, whilst younger children are more likely to allow intrusions to appear in their output (Doyle, 1973; Sexton & Geffen, 1979). Hagen (1967) attributed such developmental differences as part of the growing ability to focus attention on the task-relevant cues, and in turn recall is less susceptible to the inclusion of distracting stimuli. The implementation of an 80-20% split in the recall of focal and nonfocal items requires participants to filter necessary information in order to be successful at the task, minimising the number of irrelevant items in working memory (Cowan et al., 2010). Under such conditions, older children should be able to focus attention better on the task at hand and be less affected by distracting stimuli, regardless of whether they had been instructed to recall irrelevant information.

The interlink between WMC and selective attention within the visual domain has been investigated by Cowan and colleagues (2010, 2011) in children. The authors used visual arrays in simultaneous (Cowan et al., 2010) and interleaved (Cowan et al., 2011) presentation formats to report younger children held fewer items in working memory, indicative of a developmental increase in visual WMC. However, age-related differences in the allocation of attention between attended and unattended stimuli was only evident when the memory load was large relative to WMC. Therefore, developmental differences in WMC within this domain were not down to their ability to allocate attention effectively. The SIIT has similarities to Cowan's work in terms of presentation order and an 80-20% split of high- and low-priority information. The experiment lends itself to explore the extent to which Cowan et al's findings are generalisable in a different context, exploring age-related differences in the proportion of focal and nonfocal recall, indicative of an effective use of selective attention.

Following on from Cowan's suggestions that visual WMC is not dependent on the allocation of attention, presentation modality was considered. As part of understanding the cognitive profile of PM stimuli were presented either in a visual, auditory or combined visual and auditory format. The variation in presentation modality investigated whether PM capacity and attentional processes are modulated by the nature of representational codes (See Penney, 1989 for a review). Experiments using serial recall have produced findings whereby auditory presentation produces a stronger recency advantage than the visual presentation (Cowan et al., 2002). In addition, the free recall literature also states the recency effect to be susceptible to the modality effect (Craik, 1969; Murdock & Walker, 1969; Watkins, 1972), i.e. an auditory advantage in the recall of immediate information. It has been suggested that auditory information has privileged or obligatory access to some cognitive systems (McLeod & Posner, 1984; Salamé & Baddeley, 1982). However, within the context of dichotic listening paradigms, Martin (1978) found that both visual and verbal attended memory items demonstrated a large drop in recall when unattended items were recalled first. This suggested that all attended items are in a store, which is either rapidly decaying or susceptible to response interference, synonymous with the argument of a unitary short-term store or PM. Therefore, the current experiment provides the opportunity to explore how different presentation modalities affect the attentional capture (what gets noticed) and the regulation (the impact of active maintenance) of target information in children aged five- to eight-years and adults.

This chapter directly addresses the theoretical discrepancies described above when ascertaining the development of PM and SM in children and their contribution to the development of WMC. Free recall tasks with manipulations of list length and presentation rate were administered to adults and children. Firstly, serial position effects were analysed to determine age-related differences in primacy and recency effects. Alongside this, individual differences in recall strategies were examined. This analysis should evaluate whether it is possible to observe age-related increases in both primacy and recency effects, despite previous findings. The inclusion of different list lengths and presentation rate should provide a more detailed understanding of how children react to such manipulations in comparison to adults. Based on this, it will also impact how PM and SM are used differently across the different age groups. As part of Experiment 1, this chapter also applies Tulving and Colotla's method to children's free recall data, assessing the use of ITRIs to determine the extent to which such methods are reliable. Finally, the derived estimates of PM and SM will be used to examine their individual contributions to WMC. This provides the opportunity to compare the two participant groups to determine whether children use PM and SM differently to adults.

The independent SIIT task was tested as an alternative measure of whether PM capacity does increase through childhood. Alongside this the task investigated the cognitive mechanisms that underlie this specific memory system that contribute to its development and how different presentation formats affect the maintenance of memory representations within the immediate memory system. Overall, this should provide a detailed understanding of how PM and SM develops through childhood and the accessibility of memory items from immediate memory, as part of our understanding of the development of WMC.

2.2 Method

2.2.1 Participants

Eighty children were recruited from three primary schools in the North-West of England, having obtained parental consent in each case. Children were classified by UK school classes: Year 1 (five- to six-year olds; N = 40, M = 6:02 years, range: 5:07-6:11 years, 25 female), and Year 3 (seven- to eight-year olds; N = 40, M = 8:00 years, range: 7:02-9:00 years, 21 female). Forty-four undergraduate students were recruited from the University of Lancaster, all of whom gave full consent to undertake the study. The mean age of adults was 20:08 years (range: 18:00-34:05 years, 35 female).

2.2.2 Materials

A stimulus pool of 380 words was extracted from the Medical Research Council (MRC) linguistic database (Wilson, 1988) for three experimental tasks: free recall, listening span task and the interleaved items task. All stimuli were monosyllabic, concrete nouns, with age of acquisition ratings below 6.2 years (Wilson, 1988). This was in accordance with the mean age of the youngest, five- to six-year age group. These items were presented both auditorily and pictorially. The stimuli were recorded in a male voice; each recording lasting 750 milliseconds(ms). In order to ensure all auditory stimuli were the same length, silence was added to the end of recordings where necessary. The coloured pictures presented for the free recall were the same visual stimuli used by Hall et al., (2015) and supplemented with additional items.

2.2.3 Design and Procedure

All participants took part in all experimental tasks, following a within-subjects design. The order of tasks within the session were counterbalanced across participants. Overall, the testing session lasted approximately 40 minutes. The task was programmed using Livecode 5.5, delivered on a 15-inch screen MacBook laptop. Individual testing sessions for children took place in a quiet, classroom setting. Adults were tested in a laboratory setting in the Psychology Department, Lancaster University.

2.2.4 Free recall

List length (eight-items and ten-items) and presentation rate (1s and 2s) was manipulated in a blocked format. In total there were four blocks each comprising six trials (Appendix I). The list lengths chosen should be sufficient to generate serial position curves in the sampled age groups. The presentation rate was based on the work in adults (Murdock, 1962) and children (Murray & Roberts, 1968). The 1s rate discouraged any strategic rehearsal processes, whilst the slower 2s rate enabled the opportunity for participants to do so. Once the presentation of a list finished, participants were asked to recall all the items they could remember in any order. The serial position and order of correct recall were recorded.

In order to gather estimates of PM and SM, all the free recall data from Experiment 1 were coded in regards to Tulving and Colotla's (1970) method. ITRIs were calculated for every recalled item. An ITRI is the sum of intervals between the serial position of when the item is presented and its position at recall. If an item had an ITRI of seven or below, it was categorised as PM, whilst an ITRI of eight and above is categorised as SM. Table 2.1 provides an example of how recalled items were categorised.

Table 2.1: An example of the calculation of ITRIs from free recall output.

Serial Position	1	2	3	4	5	6	7	8	PM	SM
Recall Order	3	4					2	1	-	-
ITRI	9	9					2	0	2	2

2.2.5 Serial interleaved items task (SIIT)

Children were assigned to one of three presentation conditions: visual (coloured illustration only, Year 1: N = 13; Year 3: N = 13; Adults: N = 15), auditory (spoken words, Year 1: N = 14; Year 3: N = 13; Adults: N = 12) and dual presentation (both presentation forms occurred simultaneously, Year 1: N = 13; Year 3: N = 14; Adults: N = 13). This task involved two characters, Spongebob and Patrick, distinguished by two male voices and coloured illustrations of the characters (See Figure 2.1). Participants were instructed to try and remember Spongebob's items (focal items) and ignore Patrick's items (nonfocal items), ensuring that the recall of focal information was the focus. Presentation consistently began with a focal item on the left hand side of the screen and then alternated with the nonfocal stimuli on the right hand side. The task included 20 trials with list lengths ranging from three- to six-items in total. For example list length three included the alternation of two focal items and one nonfocal item. The presentation of list lengths was pseudo-randomised.

After stimulus presentation, 80% of lists were followed with a highlighted red speech bubble appearing above Spongebob, indicating the recall of focal items. For the remaining 20% of trials the red speech bubble appeared above Patrick, indicating the recall of non-focal items. The position of the red speech bubble was distributed randomly and therefore participants were unaware of where it was going to appear on each trial. Participants were instructed to use serial recall, thus recalling the focal items in the order in which they were presented.

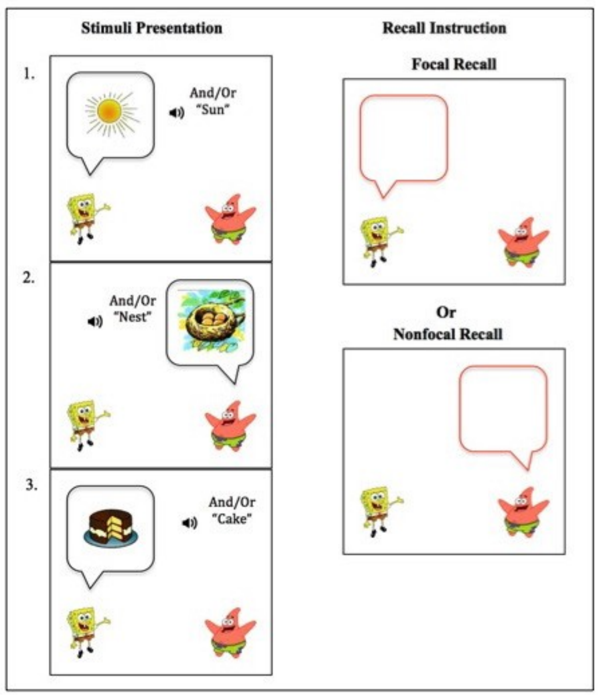

Figure 2.1: A schematic demonstration of the serial interleaved items task (SIIT).

2.2.6 Listening span task

The listening span task was adapted from procedures described in Threadgold (2012). Participants listened to sentences whilst trying to remember a set of unrelated words. List length increased sequentially from two- to five-items, with three trials at each list length, generating twelve trials. Forty-two sentences were used, half of which were "silly" (i.e. semantically inappropriate); the other half were not (based on early acquired semantic information), for example "A book is a musical instrument" in contrast to "I can see with my eyes "). If children thought the sentence was silly they pressed "Y" on the keyboard; otherwise "N". Immediately following this response, the unrelated word was presented in a different voice to that of the preceding sentence. At recall, participants were instructed to recall words in serial order. The dependent measure was the overall proportion of correct recall across the 42 trials.

2.3 Results

2.3.1 Serial position effects

In order to examine the developmental differences in primacy and recency effects within the free recall task, two measures were applied: the probability of first recall (PFR) and the probability of recall (PR). PFR is the probability of which serial position participants began their recall, whilst PR is the probability of each serial position subsequently being recalled. Both types of measurement are calculated by the number of times an item at each serial position was recalled divided by the total number of trials. The two measures were used to generate serial position curves, which were further investigated using multiple pairwise comparisons with a Bonferroni correction. This determined differences in the size of the primacy and recency effects. Using PFR and PR as the dependent variables, both measures were used to examine age-related differences in the impact of list length and presentation rate on free recall performance. Presentation rate was incorporated into the analysis of each list length, but to determine the effect of list length, the first and last three serial positions of each list length were compared. Overall, this should provide a detailed examination of whether adults and children react in a similar fashion, supporting the findings of existing literature.

2.3.2 Probability of First Recall (PFR)

Where do adults and children begin their recall? Two separate mixed factor ANOVAs were carried out for the two different list lengths, with PFR as the dependent variable. Therefore, the ANOVAs included serial position (eight- or ten-items) x presentation rate (1s vs. 2s) x age (Year 1 vs. Year 3 vs. Adults).

The final serial position of each list was the most likely starting point for recall for both list lengths (eight-items: $F(7,819) = 148.179$, $p < .001$, $\eta p^2 = .559$; ten-items: $F(9,1053) = 182.721$, $p < .001$, $\eta p^2 = .610$). Within the eight-item lists, a higher PFR was produced at the 1s rate ($M = .127$; $SE = .001$) than the 2s rate ($M = .123$; $SE = .001$), $F(1,117) = 12.061$, $p < .001$, $\eta p^2 = 093$, but no effect of age was evident, $F(2,117) = .207$, $p = .814$, $\eta p^2 = .004$. In contrast, the ten-item lists showed age related differences in where participants began their recall, $F(2,117) = 3.845$, $p = .024$, $\eta p^2 = .062$, but there was no effect of presentation rate, $F(1,117) = .525$, $p = .470$, $\eta p^2 = .004$.

Both list lengths also showed a significant interaction between serial position and age (eight-items: $F(14,819) = 12.009$, $p < .001$, $\eta p^2 = .170$; ten-items: $F(18,1053) = 13.240$, $p < .001$, $\eta p^2 = .185$). Both were attributed to differences in whether adults and children began their recall with the first or last item (Figure 2.2). Adults were equally likely to begin their recall with the first or last serial position (eight-items: $F(1,39) = .046$, $p = .832$, $\eta p^2 = .001$; ten-items: $F(1,39) = .449$, $p = .507$, $\eta p^2 = .011$). Both groups of children showed a higher likelihood to begin recall with the final list item than the first item (Year 1 eight-items: $F(1,39) = 130.886$, $p < .001$, $\eta p^2 = .770$; Year 1 ten-items: $F(1,39) = 155.133$, $p < .001$, $\eta p^2 = .799$; Year 3 eight-items: $F(1,39) = 66.804$, $p < .001$, $\eta p^2 = .631$; Year 3 ten-items: $F(1,39) = 121.828$, $p < .001$, $\eta p^2 = .759$)

Both list lengths generated a significant interaction between presentation rate and serial position (eight-items: $F(7,833) = 6.949$, $p < .001$, $\eta p^2 = .512$; ten-items: $F(9,1053) =$

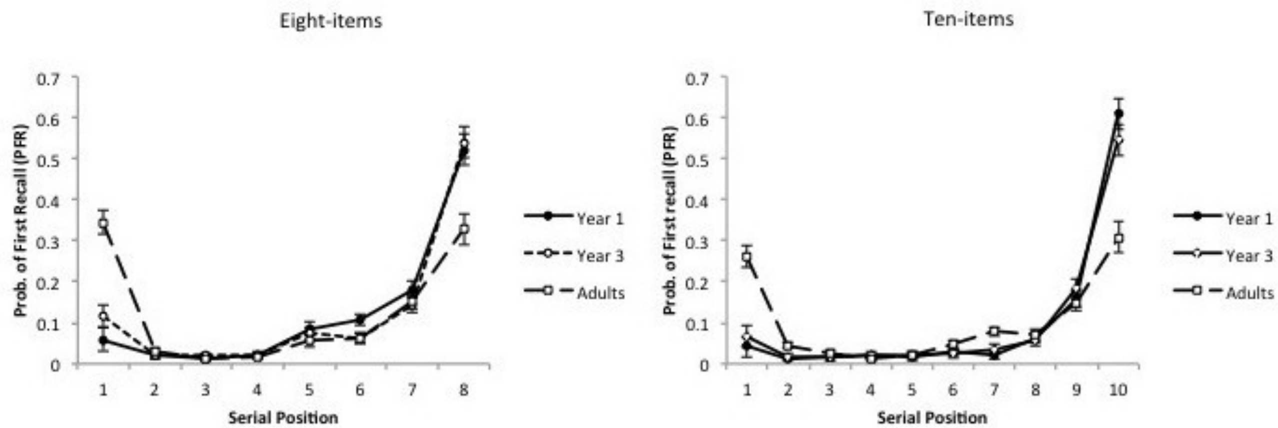

Figure 2.2: Probability of first recall (PFR) as a function of serial position and age for the eight- and ten-item lists. Error bars represent one standard error from the mean.

2.125, $p = .025$, $\eta p^2 = .018$). The eight-item lists showed participants were more likely to begin recall with the recency positions six and seven at the 1s rate, (position six: $t(119) = 2.017$, $p = .046$; position seven: $t(119) = 3.328$, $p < .001$), whilst the last serial position generated the higher PFR at the 2s rate, $t(119) = 3.365$, $p < .001$. The ten-item lists showed the 2s rate produced a higher PFR at serial position four, $t(119) = 2.328$, $p = .022$; whilst the 1s rate produced higher PFRs at positions seven and nine (position seven: $t(119) = 2.111$, $p = .037$; position nine: $t(119) = 2.052$, $p = .042$). Neither list lengths showed a three-way interaction between the three variables (eight-items: $F(14,819) = .804$, $p = .665$, $\eta p^2 = .014$; ten-items: $F(18,1053) = .610$, $p = .894$, $\eta p^2 = .010$).

The first and last serial positions were the most likely points that participants began their recall. It was necessary to determine whether the size of the list affected the extent to which participants began recall with these two specific positions. A 2 (serial position: first vs. last) x 2 (list length: eight-items vs. ten-items) x 3 (age: Year 1 vs. Year 3 vs. Adults) mixed factor ANOVA produced a significant effect of serial position, $F(1,117) = 110.694$, $p < .001$, $\eta p^2 = .486$, indicated that participants were more likely to begin their recall with the last serial position (M = .475; SE = .020) in comparison to the first (M = .148; SE = .015), with no main effect of list length, $F(1,117) = 1.820$, $p = .180$, $\eta p^2 = .015$. However, the interaction between list length and serial position highlighted that PFR for the first item decreased as a function of increasing list length, $F(1,117) = 11.916$, $p = .001$, $\eta p^2 = .092$, whilst the probability of beginning with the last item remained the same, $F(1,117) = 2.025$, $p = .157$, $\eta p^2 = .017$ (Figure 2.3). This was consistent across age groups, reflected in the non-significant three-way interaction, $F(2,117) = .449$, $p = .639$, $\eta p^2 = .008$.

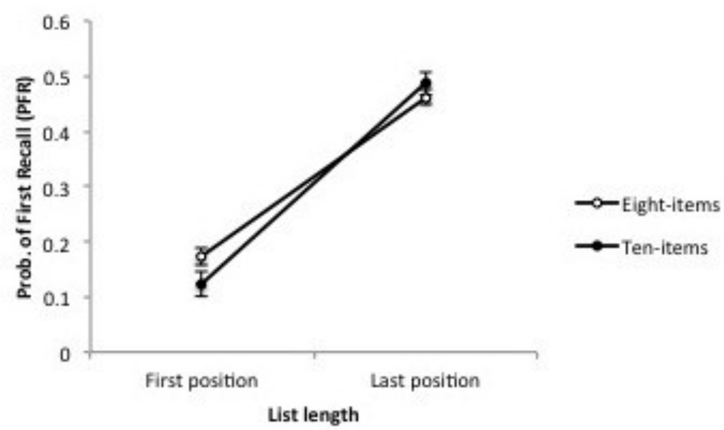

Figure 2.3: Probability of first recall (PFR) as a function of list length and the first and last serial positions. Error bars represent one standard error from the mean.

2.3.3 Inter-individual differences in recall initiation strategies

Using the PFR analysis, all participants were categorised into three recall strategy subgroups, modelled after Gibson et al. (2010) and Unsworth et al. (2011). The primacy subgroup was categorised by having a greater aggregate PFR for the first three serial positions (primacy) than the last three positions (recency), quantified by a .10 difference (Unsworth et al., 2011). Categorisation of the recency subgroup was the opposite. If the difference was not met participants were placed in the combination group, reflecting a combination of primacy and recency initiation strategies. The four free recall conditions collected from the current dataset was collapsed and the total percentage of each subgroup was calculated. Table 2.2 compares the current dataset with the published data from Gibson et al., (2010) and Unsworth et al., (2011).

Table 2.2: The frequency of participants in each subgroup across experiments and age group.

Data	Primacy Group	Recency Group	Combination Group
Current data			
Year 1 (5-6 years)	1.26%	91.86%	6.88%
Year 3 (7-8 years)	2.50%	86.87%	10.63%
Adults (18-34 years)	26.24%	50.63%	23.13%
Gibson et al. (2010)			
11-14 years ADHD	21.88%	56.24%	21.88%
11-14 years Control	32.26%	51.61%	16.13%
Unsworth et al. (2011)			
Adults (18-35 years)	20.00%	45.33%	34.67%

This confirms the previous analysis that the majority of children in both age groups began their recall with the last items in a list. Very few children were categorised in the combination group, and even fewer in the in primacy subgroup. The adolescent and adult data also showed the recency subgroup to hold the largest percentage but by a much smaller margin, with increasing percentages of adolescent and adult participants being categorised into the primacy group. Given the distribution of data across the different population samples and three different subgroups, formal analysis was not straightforward. However, it does provide qualitative evidence that converges with the previous analyses in section 2.3.2 of a recency dominant recall initiation strategy in children aged five- to eight-years. Although, it is also evident that as age increased there was an increase in the percentage of participants beginning their recall with primacy items, or using a combination of both primacy and recency strategies.

2.3.4 Probability of Recall (PR)

Serial position curves illustrated the effect of age and presentation rate on children and adults' recall performance (see Figure 2.4). Both analyses revealed age-related increases across all three groups (eight-items: $F(14,117) = 189.922$, $p < .001$, $\eta p^2 = .765$; ten-items: $F(2,117) = 202.477$, $p < .001$, $\eta p^2 = .776$). Significant effects of serial position (eight-items: $F(7,819) = 235.070$, $p < .001$, $\eta p^2 = .668$; ten-items: $F(9,1053) = 275.079$, $p < .001$, $\eta p^2 = .702$), and the multiple pairwise comparisons highlighted participants' recall was most accurate for the final list items, indicative of a recency effect. Within the eight-item lists, the last two positions (position seven = .659; position eight = .865) not only significantly differed from each other, but were recalled significantly more than all preceding serial positions (all $ps < .01$). For the ten-item lists, most accurate recall was produced between serial positions eight and ten (range: .416-.862). The primacy effects were not as clear. Within the eight-item list, the comparison of serial positions one to six were non-significant (range from .306-.416), whilst the ten-item list showed elevated recall at positions one to three (range: .276-.333), in comparison to positions four to seven (range: .207-.277). Presentation rate did not affect PR for either list lengths (eight-items: $F(1,117) = 3.511$, $p = .063$, $\eta p^2 = .029$; ten-items: $F(1,117) = .624$, $p = .431$, $\eta p^2 = .005$).

Both list lengths showed a series of significant interactions between serial position and age (eight-items: $F(14,819) = 24.142$, $p < .001$, $\eta p^2 = .292$; ten-items: $F(18,1053) = 13.536$, $p < .001$, $\eta p^2 = .188$), presentation rate and age (eight-items: $F(2,117) = 9.961$, $p < .001$, $\eta p^2 = .145$; ten-items: $F(2,117) = 26.016$, $p < .001$, $\eta p^2 = .182$) and presentation rate

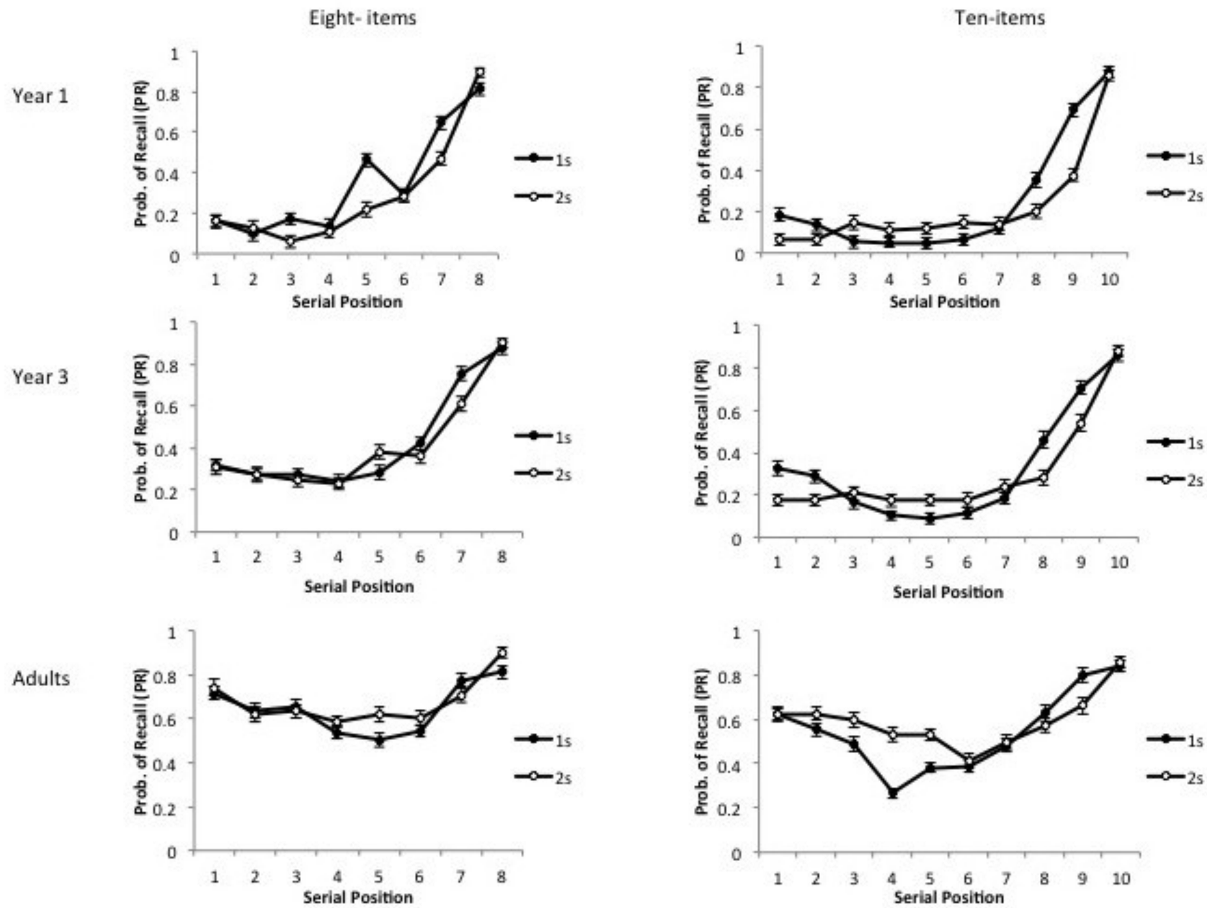

Figure 2.4: Probability of Recall (PR) as a function of serial position, presentation rate and age. Error bars represent one standard error from the mean.

and serial position (eight-items: $F(7{,}819) = 6.042, p < .001, \eta p^2 = .040$; ten-items: $F(9{,}1053) = 26.016, p < .001, \eta p^2 = .182$) leading to a three-way interaction between serial position, presentation rate and age (eight-items: $F(14{,}819) = 6.042, p < .001, \eta p^2 = .059$; ten-items: $F(18{,}1053) = 2.159, p = .003, \eta p^2 = .036$). This was attributed to developmental increases in the primacy effects investigated by comparing the first half of the eight- and ten-item lists across the three different age groups. Within the eight-item lists, Year 1 showed no indication of a primacy effect, reflected in non-significant serial position effects, $F(3{,}117) = 2.227, p = .089, \eta p^2 = .054$. Year 3 showed serial position effects, $F(3{,}117) = 3.532, p = .017, \eta p^2 = .083$, attributed to position one producing a higher PR than position four ($p = .027$), thus showing a tendency for a primacy effect, but not confirmed by statistical analysis. Adults produced a clearer division of serial positions, $F(3,117) = 10.264$, $p < .001$, $\eta p^2 = .208$, whereby the first position was significantly higher than positions two to four (all $ps < .05$), which did not differ from each other.

The ten-item lists showed that all age groups were able to produce primacy effects. All age groups generated significant serial position effects (Year 1: $F(4,156) = 10.942$, $p < .001$, $\eta p2 = .219$; Year 3: $F(4,156) = 9.708$, $p < .001$, $\eta p^2 = .199$; Adults: $F(4,156) = 17.728$, $p < .001$, $\eta p^2 = .313$), but a developmental increase in the size of the primacy effect was evident. Year 1 produced elevated recall for the first item, with a steady decline in recall for positions two to five. The primacy effect in Year 3 was extended to the first two items, which then extended to a three-item primacy effect in adults. However, it should be noted that the PR for the first serial position in the Year 1 group was very low (.171). This rose to .317 in Year 3 and .684 to adults.

Significant interactions between presentation rate and age were evident for both list lengths (eight-items: $F(7,819) = 6.042$, $p < .001$, $\eta p^2 = .040$; ten-items: $F(9,1053) = 26.015$, $p < .001$, $\eta p^2 = .182$). Year 1 recalled more items at the 1s rate in comparison to the 2s rate regardless of list length (eight-items: $F(1,39) = 21.648$, $p < .001$, $\eta p^2 = .357$; ten-items: $F(1,39) = 21.376$, $p < .001$, $\eta p^2 = .354$). Year 3 and the adults showed no differences between the two rates on eight-item lists, (Year 3: $F(1,39) = 1.745$, $p = .194$, $\eta p^2 = .043$, Adults: $F(1,39) = 3.110$, $p = .085$, $\eta p^2 = .074$). However, the recall of ten-items showed Year 3 to recall more items at the faster rate 1s rate, $F(1,39) = 4.365$, $p = .043$, $\eta p^2 = .101$, the same as Year 1. Adults recalled more items at the slower 2s rate, $F(1,39) = 9.555$, $p = .004$, $\eta p^2 = .197$.

2.3.5 The effect of list length on primacy recall

To specifically explore how increased list lengths affected participants recall, the first three serial positions of the two different lists were compared as a function of age. A 3 (serial position: position one vs. position two vs. position three) x 2 (presentation rate: 1s vs. 2s) x 2 (list length: eight-items vs. ten-items) x 3(age: Year 1 vs. Year 3 vs. Adults) mixed factor ANOVA with PR as the dependent variable was carried out. The age-related increase in PR remained, $F(2,117) = 211.530$, $p < .001$, $\eta p^2 = .783$. The comparison of list lengths showed the eight-item lists produced higher recall of the first three-items (M=.359; SE=.011) in comparison to the ten-item lists, (M=.305; SE=.012), $F(1,117) = 28.890$, $p < .001$, $\eta p^2 = .203$. Presentation rate had no effect on recall, $F(1,117) = 1.497$, $p = .224$, $\eta p^2 = .013$.

The significant interaction between serial position and presentation rate, $F(2,234) = 4.576$, $p = .011$, $\eta p^2 = .038$, revealed recall of the first list item was increased at the 1s rate, $t(239) = 2.647$, $p = .009$, whilst positions two and three showed no differences across presentation rates (position two: $t(239) = .999$, $p = .319$; position three: $t(239) = .800$, $p = .424$). However, the significant three-way interaction between presentation rate, list length and serial position, $F(2,234) = 15.862$, $p < .001$, $\eta p^2 = .119$, highlighted that the interaction between serial position and presentation rate previously described was only evident within the ten-item lists, $F(2,238) = 19.808$, $p < .001$, $\eta p^2 = .143$, not in the eight-item lists, $F(2,238) = 2.605$, $p = .076$, $\eta p^2 = .021$.

An interaction between list length and age, $F(2,117) = 3.222$, $p = .043$, $\eta p^2 = .052$ was further qualified by a three-way interaction between presentation rate, list length and age, $F(2,117) = 3.696$, $p = .028$, $\eta p^2 = .059$. The interaction between list length and age was evident at the 1s rate. Only adults recall decreased as a function of increasing list length, $F(1,39) = 17.033$, $p < .001$, $\eta p^2 = .304$, whilst Years 1 and 3 showed no difference across list lengths, Year 1: $F(1,39) = .878$, $p = .355$, $\eta p^2 = .022$; Year 3: $F(1,39) = 1.243$, $p = .272$, ηp^2

= .031. The 2s rate showed the interaction between list length and age was non-significant, $F(2,117) = 2.277$, $p = .107$, $\eta p^2 = .037$.

2.3.6 Estimates of PM and SM

In order to assess adults' and children's' recall in terms of PM and SM systems, Tulving and Colotla (1970)'s method was administered to the current data set. To confirm the effects of presentation rate and list length from the serial position analyses, the estimates of PM and SM were analysed to determine whether the manipulations affected the number of items recalled from each system (see Table 2.3). A 2 (presentation rate: 1s vs. 2s) x 2 (list length: eight-items vs. ten-items) x 2 (memory system: PM vs. SM) x 3 (age: Year 1 vs. Year 3 vs. Adults) mixed factor ANOVA with mean number of items recalled as the dependent variable was carried out. An age-related increase in the number of items recalled was evident, $F(2,117) = 227.599$, $p < .001$, $\eta p^2 = .796$, with systematic increases across the three age groups demonstrated by a Bonferroni post hoc test (all *ps* < .001). A main effect of memory system highlighted that more items were recalled from PM ($M = 2.690$; $SE = .030$) than SM ($M = 1.026$; $SE = .048$), $F(1,117) = 1033.311$, $p < .001$, $\eta p^2 = .898$. Consistent with the previous analysis, there was no effect of presentation rate, $F(1,117) = .764$, $p = .384$, $\eta p^2 = .006$, or list length, $F(1,117) = 1.390$, $p = .241$, $\eta p^2 = .012$.

Table 2.3: Age-related increases in total recall, PM and SM estimates (one standard error from the mean).

	Year 1	Year 3	Adults
Total recall	2.40 (.105)	3.26 (.105)	5.48 (.105)
PM	2.12 (.053)	2.58 (.053)	3.37 (.053)
SM	.28 (.082)	.68 (.082)	2.12 (.082)

Significant interactions between memory system and age, $F(2,117) = 16.098$, $p < .001$, $\eta p^2 = .216$, and presentation rate and memory system, $F(1,117) = 10.751$, $p < .001$, $\eta p^2 = .084$, were further qualified by a significant three-way interaction between presentation rate, memory system and age, $F(2,117) = 4.039$, $p = .020$, $\eta p^2 = .065$ (Figure 2.5). Year 1 recalled more items from PM at the 1s rate in comparison to the 2s rate, $F(1,79) = 14.707$, $p < .001$, $\eta p^2 = .157$. However, Year 3 and adults showed no difference in PM use regardless of rate (Year 3: $F(1,79) = 3.543$, $p = .063$, $\eta p^2 = .043$; Adults: $F(1,79) = .418$, $p = .520$, $\eta p^2 = .005$). In contrast, analysis of SM estimates revealed adults recalled more SM items at the 2s rate in comparison to 1s, $F(1,79) = 13.918$, $p < .001$, $\eta p^2 = .150$. Both children groups were invariant to this specific manipulation (Year 1: $F(1,79) = .831$, $p = .365$, $\eta p^2 = .010$; Year 3: $F(1,79) = 2.678$, $p = .106$, $\eta p^2 = .033$).

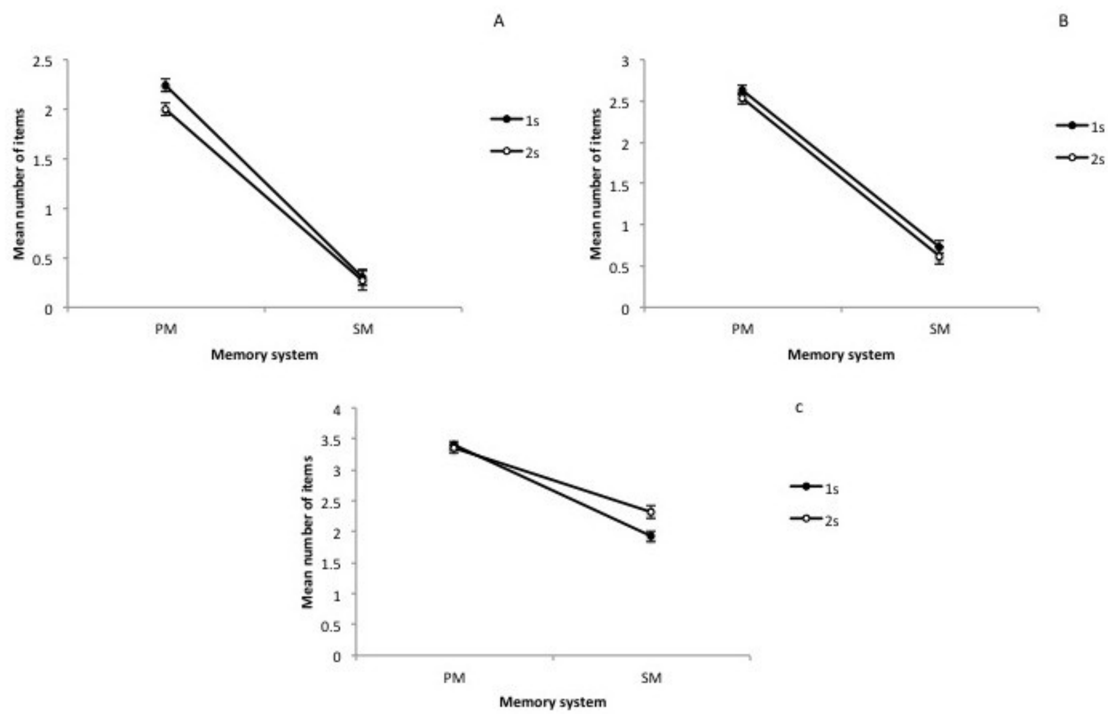

Figure 2.5: The mean number of items recalled as a function of presentation rate and memory system in Year 1 (A); Year 3 (B) and adults (C). Error bars represent one standard error from the mean.

A significant interaction between list length and memory system, $F(1,117) =$

112.584, p = .001, ηp^2 = .490, was accompanied by a significant three-way interaction between list length, memory system and age, $F(2,117)$ = 32.010, p < .001, ηp^2 = .354 (Figure 2.6). All age groups showed a trade-off between the use of the two memory systems. As list length increased, the use of PM decreased (Year 1: $F(1,79)$ = 12.514, p < .001, ηp^2 = .137, Year 3: $F(1,79)$ = 81.721, p < .001, ηp^2 = .508, Adults: $F(1,79)$ = 71.061, p < .001, ηp^2 = .474), whilst the use of SM increased, (Year 1: $F(1,79)$ = 17.865, p < .001, ηp^2 = .184, Year 3: $F(1,79)$ = 23.690, p < .001, ηp^2 = .231, Adults: $F(1,79)$ = 103.455, p < .001, ηp^2 = .567). The only exception was equivalent PM and SM use at the ten-item lists in adults, $F(1,79)$ = .013, p = .911, ηp^2 = .001.

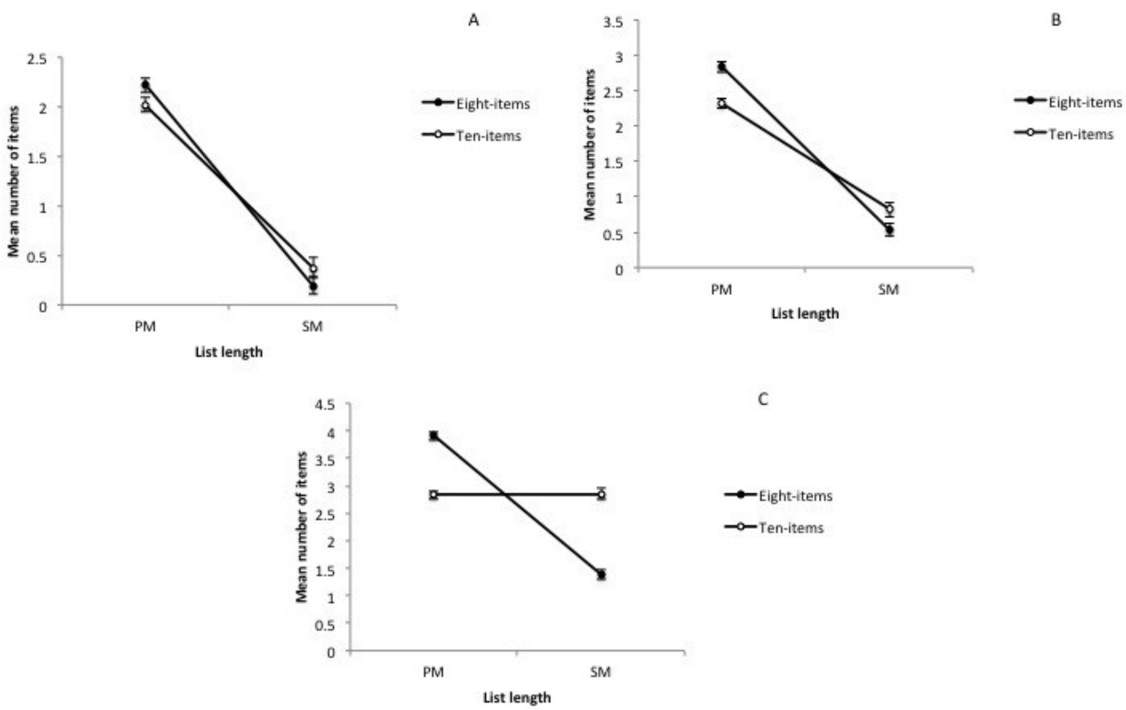

Figure 2.6: The mean number of items recalled as a function of list length and memory system in Year 1 (A), Year 3 (B) and adults (C). Error bars represent one standard error from the mean.

2.3.7 ITRI Frequency in children and adults

The critical value seven as a threshold for categorising PM and SM proposed by Tulving and Colotla (1970) is questionable in regards to its applicability to children. Therefore, as shown in Figure 2.7, the total frequency of recalled items for each ITRI was calculated to investigate whether there is a point in the frequency that shows a divide between PM and SM and a potential critical value for children. Figure 2.7A illustrated no differences between ITRIs 0-2 across the three age groups (ITRI 0: $F(2,119) = 1.935$, $p = .149$, $\eta p^2 = .032$; ITRI 1: $F(2,119) = .058$, $p = .944$, $\eta p^2 = .001$; ITRI 2: $F(2,119) = 1.182$, $p = .310$, $\eta p^2 = .020$). However, from ITRI 3 onwards, age-related increases were evident using Bonferroni posthoc tests (all *ps* $< .05$). Figure 2.7B demonstrates how the data was affected when reducing the critical value from seven to four to two.

As expected, age-related differences in PM use changed as a function of the different critical values. This was analysed using a series of univariate ANOVAs. The value seven generated the age-related increases in PM as described previously, $F(2,119) = 225.393$, $p < .001$, $\eta p^2 = .794$. The critical value four showed no differences between Years 1 and 3, but they both used PM to a lesser extent than adults, $F(2,119) = 7.074$, $p = .001$, $\eta p^2 = .108$. In contrast, the use of two as a critical value showed no differences in PM use between all ages, $F(2,119) = .593$, $p = .554$, $\eta p^2 = .010$.

The same analysis was carried out to determine whether SM use demonstrated similar age-related changes in the memory system dependent on the size of the critical value. Age-related increases were evident across all three critical values (seven: $F(2,119) = 129.748$, $p < .001$, $\eta p^2 = .689$; four: $F(2,119) = 22.794$, $p < .001$, $\eta p^2 = .791$; two: $F(2,119) = 252.290$, $p < .001$, $\eta p^2 = .812$), but the extent to which the age-related differences were evident increased as the critical value decreased.

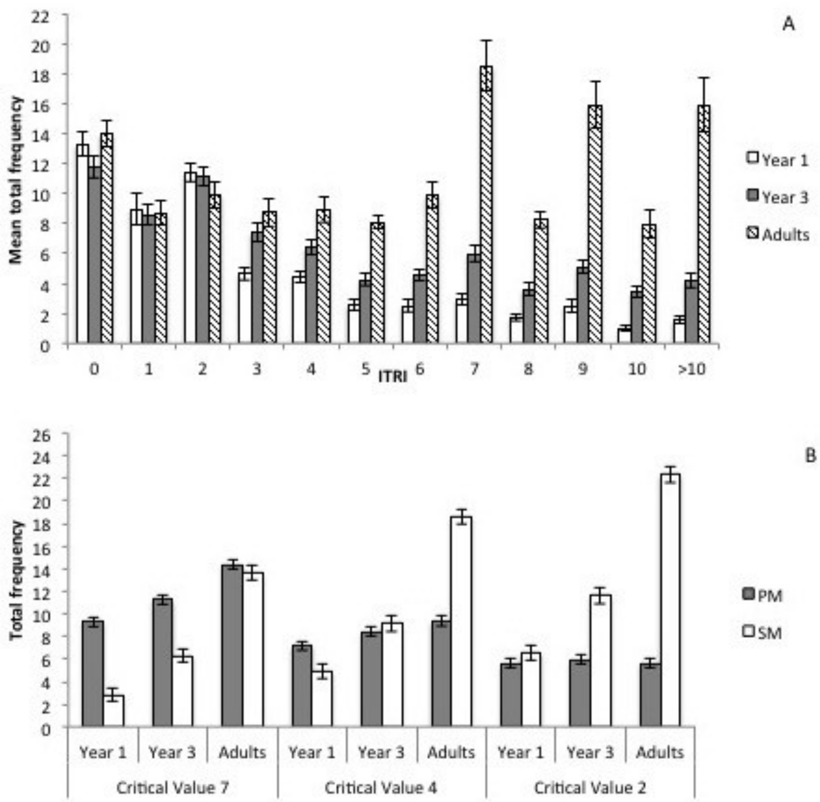

Figure 2.7: A= The total frequency of ITRIs. B= Total frequency of recall as a function of critical values and memory system. Error bars represent one standard error from the mean.

2.3.8 The serial interleaved items task (SIIT): focal recall, nonfocal recall and *k*

Three different types of analyses were used to ascertain age- and presentation modality differences in the active maintenance of items in PM. This followed a method used by Cowan et al. (2011). Participant's total recall (i.e. both focal and nonfocal information), labeled as *k*, was defined as the number of items held in working memory. PM capacity and the allocation of attention was then reflected in the proportion of items recalled from the *k* value. This was applied to both focal and nonfocal recall. Age-related and presentation modality differences were dissected using posthoc tests with a Bonferroni correction. Each of these in turn should present developmental differences in PM capacity and selective attention, with the addition of how the presentation format of memory items affects the active maintenance of the number of representations in PM.

Analysing the overall proportion of focal recall, a 3 (presentation modality: visual vs. auditory vs. dual) x 3 (age: Year 1 vs. Year 3 vs. Adults) mixed factor ANOVA was carried out. This revealed significant effects of presentation modality, $F(2,111) = 11.388$, $p < .001$, $\eta p^2 = .170$, and age, $F(2,111) = 27.488$, $p < .001$, $\eta p^2 = .331$. The visual condition ($M = .899$; $SE = .019$) produced a higher proportion of focal recall in comparison to the auditory ($M = .769$; $SE = .020$) and dual conditions ($M = .815$; $SE = .020$). The expected age-related increase in recall showed adults recalled a higher proportion of focal recall ($M = .935$; $SE = .020$) followed by Year 3 ($M = .819$; $SE = .020$) and finally Year 1 ($M = .729$; $SE = .020$, all *ps* $< .01$). However, the interaction between the two variables, $F(4,111) = 4.328$, $p = .003$, $\eta p^2 = .135$, highlighted differential age-related effects as a function of presentation formats (Figure 2.8). No age-related differences were prevalent in the visual condition, $F(2,38) = 2.546$, $p = .092$, $\eta p^2 = .118$. The auditory condition, $F(2,36) = 18.011$, $p < .001$, $\eta p^2 = .500$ showed no differences between Years 1 and 3 ($p = .127$), but children's proportion of focal recall was smaller than the adult performance (both *ps* $< .01$). The dual condition $F(2,37) = 12.348$, $p < .001$, $\eta p^2 = .400$, showed an age-related increase in focal recall between ages Year 1 and Year 3 ($p = .005$) and adults ($p = .001$), but there was no difference between Year 3 and adults ($p = .359$).

On the occasions when participants were instructed to recall nonfocal items, Year 3 ($M = .329$; $SE = .030$) recalled fewer nonfocal items than both Year 1 ($M = .472$; $SE = .030$) and adults ($M = .549$; $SE = .030$; all *ps* $< .01$), but there was no difference between the former two groups ($p = .286$), $F(2,111) = 13.651$, $p < .001$, $\eta p^2 = .197$. All three presentation formats differed from each other, $F(2,111) = 13.170$, $p < .001$, $\eta p^2 = .192$. The visual format generated the lowest nonfocal recall ($M = .340$; $SE = .031$), followed by the auditory format

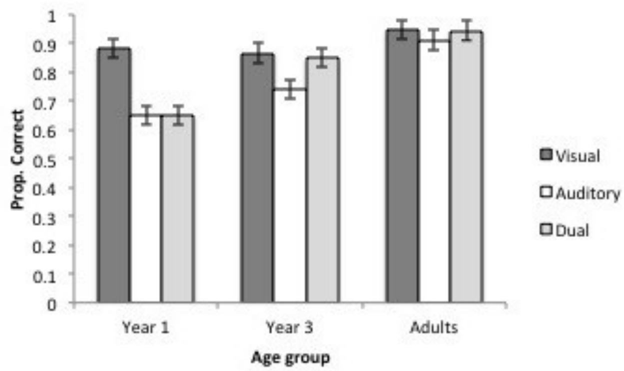

Figure 2.8: The proportion of focal recall as a function of presentation modality and age. Error bars represent one standard error from the mean.

(M = .452; SE = .031); and finally the dual condition (M = .558; SE = .030). The interaction between the two factors was non-significant, $F(4,111) = 1.768$, $p = .140$, $\eta p^2 = .060$, thus all age groups showed a similar pattern of findings as a function of presentation modality.

Figure 2.9 shows participants' mean k value as a function of presentation modality and age. Analysis confirmed adults held more items in working memory (M = 2.286; SE = .057), followed by Year 3 (M = 1.660; SE = .056) and finally Year 1 (M = 1.213; SE = .056), $F(2,111) = 90.914$, $p < .001$, $\eta p^2 = .621$. The main effect of presentation modality showed the visual condition generated the lowest k value (M = 1.563; SE = .056) in comparison to both the auditory (M = 1.833; SE = .057) and dual conditions (M = 1.762; SE = .056), $F(2,111) = 6.163$, $p = .003$, $\eta p^2 = .100$. However, the interaction between the two variables, $F(4,111) = 2.755$, $p = .031$, $\eta p^2 = .090$, showed that only Year 3 held more items in WM as a function of presentation modality, recalling more items from the dual and auditory conditions than the visual condition, $F(2,37) = 8.278$, $p = .001$, $\eta p^2 = .309$. Recall within Year 1 and adults remained stable regardless of presentation format (Year 1: $F(2,39) = 2.004$, $p = .149$, $\eta p^2 = .098$; Adults: $F(2,39) = .636$, $p = .535$, $\eta p^2 = .033$).

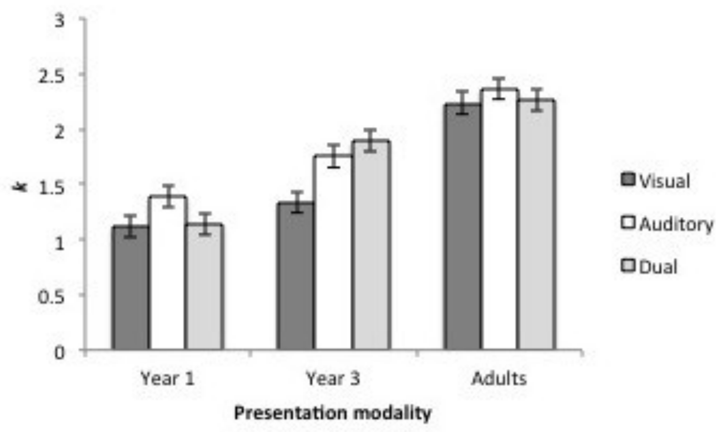

Figure 2.9: Mean number of items held in working memory (k) as a function of presentation modality and age. Error bars represent one standard error from the mean.

2.3.9 Converging measures of PM capacity

In order to investigate capacity, the mean number of items held in working memory (*k*) from the SIIT and the overall PM estimates from the free recall data were compared in a 2 (capacity: *k* from the SIIT vs. PM estimates from free recall) x 3 (age: Year 1 vs. Year 3. vs. Adults) mixed factor ANOVA (Table 2.4). This analysis revealed PM capacity was higher in the free recall task in comparison to the SIIT, $F(1,117) = 575.783$, $p < .001$, $\eta p^2 = .831$. Nonetheless, an age-related increase in PM capacity was evident, $F(2,117) = 170.552$, $p = .001$, $\eta p^2 = .745$, with systematic differences across the three age groups (all *ps* < .001). The interaction between the two factors was non-significant, $F(2,117) = 2.162$, $p = .120$, $\eta p^2 = .036$, thus indicating that despite systematic increases in capacity across the three age groups (all *ps* = .001) they all recalled more items in the free recall task in comparison to the interleaved items task .

Table 2.4: The mean PM capacity as a function of the serial interleaved items task (SIIT) and free recall estimates (one standard error from the mean).

	Year 1	Year 3	Adults
SIIT	1.22 (.060)	1.67 (.060)	2.28 (.060)
PM Free recall	2.12 (.053)	2.58 (.053)	3.37 (.053)

2.3.10 The inter-relations between WMC, focal recall, PM and SM

Table 2.5 displays the zero-order and partial correlations controlling for age between measures of *k*, focal and nonfocal recall taken from the SIIT; PM and SM estimates from the free recall task, and an index of WMC taken from the listening span task. Partial correlations, controlling for age, were generated to remove any influence of the age of participants on the inter-relations between the different memory measures. The age of the participants did not diminish the correlations to any large extent. There are consistent, significant relationships between the *k* value, WMC, PM and SM. Those who recalled more items overall in the interleaved items task showed a higher usage of PM and SM and a higher WMC. Focal recall also significantly related to the measures of WMC, PM and SM, consistent with the view that the ability to select target information is relevant to the listed memory measures. Nonfocal recall did not correlate with the other two SIIT measures, free recall or listening span measures.

Table 2.5: The correlational analysis between all experimental measures. The lower triangle reports the partial correlations controlling for age.

	1.	2.	3.	4.	5.	6.
1. *k*	-	.813***	-.047	.488***	.458***	.534***
2. FR	.756***	-	-.230*	.523***	.485***	.537***
3. NFR	.134	-.086	-	-.080	-.145	-.223*
4. WMC	.335**	.378***	.092	-	.533***	.624***
5. PMFR	.239*	.273*	.072	.349**	-	.544***
6. SMFR	.350*	.351**	-.035	.481***	.284*	-

Note. *k* = Items held in working memory; FR = Focal recall; NFR = Nonfocal recall; WMC = Working Memory Capacity; PMFR = Primary Memory Estimates from Free Recall; SM = Secondary Memory Estimates from Free Recall.

$p < .05$*; $p < .01$**; $p < .001$***

Based on the correlations, linear regression models were used to partition the variance in complex span tasks to determine the extent to which PM and SM predicts WMC in adults and children. However, the children and adults' were analysed separately to determine any differences in the extent to which the contributions of PM and SM differ. A significant proportion of variance in complex span was predicted by recall estimates of PM and SM in both children and adults, children: $R^2 = .444$, $F(3,79) = 20.244$, $p = .001$; adults: $R^2 = .432$, $F(2,39) = 14.077$, $p = .001$. Whilst SM accounted for a significant contribution of unique variance of WMC in children, $R^2 = .122$, $F(1,76) = 16.721$, $p < .001$; it was PM in adults that produced the significant unique variance when accounting for WMC, $R^2 = .298$, $F(1,37) = 19.405$, $p < .001$ (Figure 2.10).

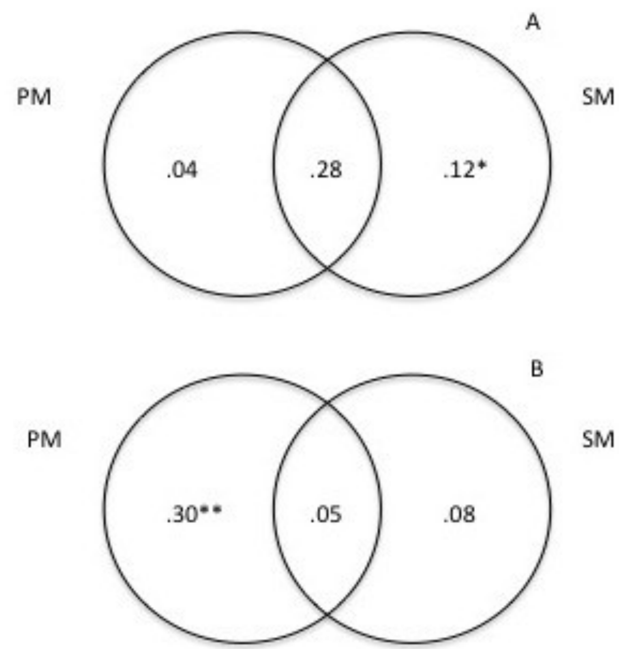

Figure 2.10: Venn diagrams showing variance partitioning with WMC as the criterion variable and predictor variables are PM and SM estimates. Children (A) and adults (B).

$p < .05^*$ $p < .001^{**}$

2.4 Discussion

This chapter sought to enrich our knowledge of the developmental increases in PM and SM as a function of WMC. Free recall measures and a complex span task were carried out to identify age-related and individual differences in PM and SM use and their relation to WMC. This was accomplished by examining where adults and children began their recall, categorising them into recall initiation subgroups and subsequent primacy and recency effects. The SIIT task further explored the cognitive profile of PM. This task is already thought to reflect PM processes (Hall et al., 2015), distinguishing between highly accessible information (PM) and search processes that operate upon more distributed and diverse representations (SM).

Illustrated in serial position curves, developmental increases were evident at both primacy and recency effects. The youngest children aged five- to six-years performed at the lowest level, which systematically increased to adulthood. The outstanding finding though is the rigidity of children's free recall strategy. Regardless of the manipulations, children used a default recency output strategy. Adults on the other hand showed a more balanced distribution of starting recall with either the first or last items in a list. The findings did reveal that as list length increased to ten-items, the probability of beginning recall with the first item decreased, whilst the probability of beginning recall with the last item remained the same. Therefore, list length does affect where adults and children begin their recall, supporting the previous literature (adults: Ward et al., 2010; children: Hall et al., 2015). In contrast, an increase in presentation rate should encourage individuals to begin recall with primacy items due to the opportunity to use maintenance strategies such as rehearsal. However, this was not the case. Participants were still likely to begin their recall within the recency section of the list. The ten-item lists removed the effect of presentation rate altogether, and all age ranges were inclined to begin recall with the last item.

Children's predominant use of a recency recall strategy was further confirmed by the categorisation into recall initiation strategy subgroups (Year 1: 91.86%; Year 3: 86.87%). Interestingly though, the evidence provided an age-related inclination to start recall with a primacy list item, and therefore a developmental decline in recency strategies. Similar work using the same method but investigating adolescents (Gibson et al., 2010) and adults (Unsworth et al., 2011) were included in Table 2.2 as a comparison. Adolescents with ADHD who demonstrated an SM deficiency generated a lower percentage of members in the primacy group, and higher percentages in the recency group, providing similarities with the children data. This suggests that the retrieval mechanism as part of SM, is not as developed and therefore such items are less accessible. Consequently, they focus their recall on the ability to retain and recall recently presented information. With reference to the adult data, it is possible to make a direct comparison between Unsworth et al. (2011)'s data and the collapsed data from the current experiment. The percentages of participants in each group were similar, providing a generality between Unsworth et al.'s findings and the current work. Consequently, the currents findings support individual differences in adult and children's free recall performance, and it must be taken into consideration when investigating PM and SM. Participants performance cannot be simplified to a universal strategy of beginning recall with recency items and then recalling items from the beginning of the list as suggested by the traditional and current frameworks using free recall as an experimental tool (Atkinson & Shiffrin, 1968; Unsworth & Engle, 2007b).

The serial position curves in Figure 2.4 showed predominant recency effects in all age groups, but it was only adults that produced clear primacy effects. These findings are not isolated, as primacy effects are usually absent in younger children (Hall et al., 2015; Hasher & Clifton, 1974; Jablonski, 1974). Despite only using a very small increase in list length, the recall of the first three-list items in the eight-item lists was greater than the ten-item lists, consistent with the adult (e.g. Ward et al., 2010) and children literature (Hall et al., 2015; Thurm & Glanzer, 1971). However, the decomposition of the three-way interaction between list length, presentation rate and age showed that this effect was only evident in adults at the 1s rate. The slower presentation rate provided the opportunity for adults to rehearse primacy items, and therefore primacy recall was elevated on both list lengths, consistent with previous findings (e.g. Rundus, 1971). However, the same explanation cannot be applied to the children's dataset. As illustrated in Figure 2.4, children were recalling close to floor in the recall of primacy items. Therefore, performance was at its lowest regardless of the manipulation, fitting with their default recency recall strategy.

A slower presentation rate provided the opportunity for participants to engage in rehearsal (Tan & Ward, 2000). Therefore, the size of the primacy effect at 2s should be larger and more accurate. However, the decomposition of presentation rate within the eight-item lists and its interactions with age and serial position showed that Year 1 recalled more items at the faster rate, whilst neither Year 3 or adults were affected. The increase to ten-items saw both Years 1 and 3 produced a higher level of recall at the 1s rate, whilst the adult PR increased at the slower presentation rate as expected. The Year 3 findings at the shorter presentation rate support Murray and Roberts (1968), demonstrating no change in performance despite different presentation rates. However, the combination of the increased list length and presentation rate generated the opposite to the desired effect, similar to how the youngest children reacted to the manipulation. It has been suggested that by seven- to eight-years of age, with the emergence of rehearsal (Flavell et al., 1966; Gathercole et al., 1994), children should demonstrate a developmental increase in the controlled use of SM(Engel de Abreu et al., 2010). However, the current data suggests otherwise, despite the oldest children being the age at which this should be observed. This is potentially due to the free recall task itself. It is mentally fatiguing and it is hard for any child to maintain their concentration. At five- to eight-years old, rehearsal strategies are only starting to emerge, and therefore they have limited coping mechanisms to be successful at the task. By doubling the presentation rate of an already very difficult task, children find it even harder to sustain their attention at the encoding and retrieval of pre-recency items, which is detrimental to their recall performance.

One reason for using the different list lengths and presentation rate was to determine how it affects the interpretation of the primacy and recency effects generated, and therefore PM and SM. Evidence from both manipulations demonstrated that children do not react in a similar manner to the documented reactions of adults. Extending the number of items children have to encode may have a detrimental effect on their primacy recall, providing findings that are confounded by other issues such as mental fatigue or control processes. The same considerations need to be applied to presentation rate. Children do not perform in the same manner as adults, as a consequence of not having the control processes and maintenance strategies in place to store information that has been displaced from immediate memory. Therefore, experimenters need to consider this when designing the free recall experiments for children.

Tulving and Colotla's method was used to categorise partcipants' recall into PM and SM. Children's predominant PM estimates in comparison to SM, fitted with the dominant recency effects in comparison to the less established primacy effects. Year 1 were not susceptible to differences in list length, whilst Year 3 recalled more items from the shorter eight-item lists. In contrast, adults recalled more items from the ten-item lists. Because children's recall was heavily PM based, and increases in list length are meant to influence SM recall, it is not surprising that the younger children were not affected by this manipulation. However, their recall was not expected to diminish as demonstrated by Year 3.

Despite different reactions to the manipulation of list length, all age groups showed a trade-off between PM and SM, suggesting one memory system was used at the expense of another. At the surface one may consider a shift in the use of memory systems as part of the management of information being maintained in working memory. However, an alternative explanation is the strict value seven affecting the classification of recalled items into PM and SM. For example, within the ten item list, if the first item is recalled first, it's ITRI is calculated as nine, as opposed to it being seven for the eight-item list. Therefore, as list length increases, more items are calculated with an ITRI of eight and above, and thus categorised as SM, leaving fewer items recalled from PM.

As stated by Craik (1970), presentation rate should increase participants overall recall, but especially impacting items from SM. Only adults use of SM increased, conforming to the adult literature. Children's recall of SM items was not affected by presentation rate. If children's ability to use maintenance strategies and rehearsal have not emerged yet, as discussed above, it is not entirely surprising that they were unable to take the opportunity to rehearse memory items. The fact that that Year 1 recalled more PM items from the faster presentation rate is possibly an indication that the longer presentation period made it harder tor children to actively maintain items, leaving them susceptible to being forgotten.

Despite Tulving and Colotla's method generating developmental increases in PM and SM estimates, the application of Tulving and Colotla's method needs to be treated with caution. The critical value of seven was chosen as a consequence of Miller's (1956) 'magic number seven'. Shipstead et al. (2014) stated that the critical value seven provided PM estimates of three- to four-items similar to the descriptions from the dual-component framework (Unsworth & Engle, 2007b) and adults' focus of attention (Cowan, 2001). It is unlikely that children, especially younger children, fit the justification of the critical value, as developmental increases in short-term memory and the focus of attention are established, believed to be synonymous with PM. Therefore, the adult threshold does not necessarily accommodate the smaller PM capacities, causing an underestimation of SM, and an overestimation of PM.

Figure 2.7 presented a profile of the lags generated in recall, as a means to reflect PM and SM use and how the method by Tulving and Colotla (1970) may affect the estimations of the independent memory systems. Jarrold et al. (2015) suggested lowering the ITRI threshold to produce more reliable estimates of PM and SM in children. By reducing the threshold to four and then two, had a huge impact on the profile of the development of PM and SM. The original critical value seven generated the developmental increases in PM, as also shown in the serial position effects. The use of four still shows PM estimates in children to be smaller than adults, but the children groups do not differ from each other. By reducing the value to two, all age differences are lost. This is not surprising as it was evident that all participants were able to recall the last items in the list. One cannot fully justify lowering the threshold as the value chosen would be just as arbitrary as the original assumption made by Tulving and Colotla (1970). Future work needs to consider different age-related thresholds that best capture PM capacity, thus reducing the possibility of over estimating one memory system at the expense of underestimating another. However, it also highlights the need to develop independent measures of PM and SM that are more sensitive to the cognitive processes and mechanism that underlie the memory systems.

Further consideration also needs to be applied to the method's assumption that participants have to begin their recall at the recency section of the list. As previously stated, individual differences in where participants began their recall was evident, and therefore, the method should only be used on those that were categorised into the recency group. This was not a problem with the children as they predominantly used a recency based strategy. However, 49.3% of adults either began their recall at the primacy section or used a combination of primacy and recency strategies. Therefore, this further reinforces the literature's lack of sensitivity surrounding how participants carry out free recall tasks and how their recall is categorised into a dual-memory framework.

Does PM and SM contribute to WMC in the same way in adults and children? Complex span tasks are typically used to index WMC, and reflect the contributions of both PM and SM. Unsworth and Engle (2006a) proposed that complex span tasks are pre-dominantly SM based, due to the interleaved processing and storage of items. Both sets of correlations showed PM and SM to positively correlate with WMC, thus those individuals with a higher WMC, were also more likely to show a higher use of PM and SM in comparison to those with a lower WMC. This is in support of Unsworth and Engle (2007b)'s comments that this specific explanation of WMC required the division of the ability to actively maintain items in PM, but also controlled cue-dependent search processes to retrieve items from SM. However, the regression analyses of adults and children separately showed PM to be a higher predictor of WMC in adults, whilst SM was a higher predictor in children. The majority of children began their recall with the last list items, and subsequently used a PM-based recall strategy, but it is the more limited SM processes that are relevant to understanding complex span performance. Adults on the other hand were more likely to show a primacy or combination related strategy and therefore it is the opposite, and PM processes drive complex span performance. Therefore, there may be a developmental shift towards the relevance of PM processes in adulthood. The dual-memory framework offers an important perspective on the components of memory that sustain individual differences in complex span, but it seems that these components are not developmentally fixed.

One also needs to be wary of the ease of the task for adults. The majority of the variance was held by PM, which suggests that this memory system is being used to store and process the complex span information. This may be due to the task being too simple for the adults and thus they are able to actively maintain the storage items in PM, even when carrying out the processing element of the task. Future work needs to investigate this finding further varying the difficulty and extending the list lengths used within the complex span task to see whether SM as a predictor of WMC increases with such manipulations.

In summary, the analysis of free recall data has shown not only developmental increases in overall recall, but also developmental increases in PM and SM capacities, supported by serial position analyses and a categorisation method. At five- to six-years of age children find it very difficult to recall information that has not just been immediately experienced. Therefore, being given more information to remember has the propensity to weaken children's performance. Even when given more time to encode memory items, they are not able to use it to their advantage. In comparison, adults are able to use the opportunity to recall more information when the amount of information available is extended and they have a longer time period to encode such information. From a methodological point of view, the experiment has also provided important insight into the classification of participants' recall performance into the two memory systems. Future research needs to be wary of how the choice of different thresholds affects the profile of PM and SM estimates when investigating the development of the cognitive systems.

The methods used to ascertain PM and SM estimates has its weaknesses. Therefore, other measures need to be considered when investigating the developmental trajectory of these systems and their relation to WMC. The SIIT was used to support the free recall findings and the notion of a developmental increase in PM capacity, but also shed light on the attentional processes that underlie this specific memory system. In addition, to further extend our understanding of PM and its development, three different presentation modalities were also introduced, thought to be evident only in PM as described in the free recall literature (Craik, 1969; Murdock & Walker, 1969; Watkins, 1972), but was not incorporated into Unsworth and Engle's (2007) dual-memory framework. Therefore, this questions how different representational codes impact the attentional underpinnings of PM and in turn its capacity.

A developmental increase in the number of items held in working memory (*k*), and the recall of focal items was evident across the age range. This provided direct evidence of age-related increases in the number of items actively maintained in PM, supportive of the argument that PM capacity does increase through childhood (Hall et al., 2015; Jarrold et al., 2015). The evidence supporting developmental increases in PM capacity ran alongside a developing efficiency in attentional allocation. This was demonstrated not only in the age-related increase in the recall of focal items, but also developmental differences in the recall of nonfocal items. Nonfocal recall was taken as an index of ineffective selective attentional mechanisms required for this task, consequently leading to the processing and recall of low priority information. A developmental decrease in nonfocal recall was evident between Years 1 and 3, however, adults produced equivalent levels of this measure with Year 1.

One potential explanation is the use of different attentional strategies across the three age groups. The decrease in nonfocal recall between the children groups is an example of the development of children focusing their attention to carry out task instructions. Year 1 potentially found it difficult to prioritise which information was processed and distributed their attentional resources between focal and nonfocal recall. In contrast, the older group of children just focused on one input (focal recall), at the expense of the other (nonfocal recall). This is consistent with Geffen and Sexton (1978), who showed age-related differences in the division of attention dependent on the task instructions. By the age of seven years, children are able to allocate priorities to channels of input in order to maximise their performance (Sexton & Geffen, 1979). In contrast, adults' performance is a combination of attentional allocation, but also their larger PM capacity. It is possible that adults were able to actively maintain the majority of items presented (a maximum of six-items). At the point of recall, adults then selected focal or nonfocal items depending on the recall instruction. Thus, attentional mechanisms are required in the maintenance and management of immediate memory items. However, the type of attentional strategy used is dependent on PM capacity itself and at what stage of attentional development the individual has reached.

The modality effect is believed to be specific to PM, based on the free recall literature (Craik, 1969; Murdock & Walker, 1969; Watkins, 1972), however it is not an element of the dual-memory framework. PM is described by Unsworth and Engle (2007b) as a combination of domain- general attentional control to allocate attention and basic memory abilities. Nonetheless, modality differences were evident for all three measures, but not necessarily in the manner expected. The *k* values showed Year 3 recalled more auditory and dual items in comparison to the visual condition, whilst Year 1 recalled a consistent number of items regardless of the presentation format. Despite these findings, the visual condition produced the highest proportion of focal recall in comparison to both auditory and dual conditions, demonstrating equivalent levels of recall across the age ranges. This was attributed to a labelling effect. Vocal naming of only focal items reduced the requirement to filter out irrelevant information, as nonfocal items were never verbally encoded, therefore not impacting any verbal-based rehearsal or recall system. The action of vocal naming potentially produced an auditory and visual memory representation of the stimuli. The auditory representation may then act as rehearsal for the visual item (Jablonski, 1974). This also explains why all age groups recalled the fewest nonfocal items when items were presented visually and consistent with Cowan et al. (2011) of whom found no age differences in the allocation of attention when investigating the developmental increases in visual WMC.

In contrast, the auditory presentation format produced a lower level of focal recall, but a higher level of nonfocal recall in comparison to the visual format. Auditory information is thought to have obligatory access to cognitive systems (McLeod & Posner, 1984; Salamé & Baddeley, 1982). Due to its obligatory access, this hindered individuals of all ages in the selective maintenance and recall of target information in the auditory domain. In particular, it was much harder for children to not process and ignore prepotent auditory information. Interestingly, the dual condition generated an age-related increase in focal recall between Years 1 and 3, but no difference between Year 3 and adults. This suggests a change in how children maintained information presented in a dual format. The five- to six-year olds were able to recall focal visual items if they had labeled them, but they did not use it as an additional support for the dual condition, as they recalled equivalently low levels of focal items in the auditory and dual conditions. By the age of seven- to eight-years, the combination of labeled visual items and enduring auditory information at input enhanced the recall of focal items, similar to how adults managed the maintenance and recall of the same items. This also stands true in participants' recall of nonfocal information. The combination of auditory and visual formats created the most robust memory representations, making such items more accessible and therefore the hardest to ignore in PM.

The modality differences described above are suggestive of the differing presentation formats and the nature of their representational code affecting the attentional capture, and therefore the active maintenance and recall of information. However, supportive evidence of domain-generality was provided by the adults who only showed a modality effect in the nonfocal recall measure. Therefore, the number of items held in working memory and the proportion of focal recall was not affected by presentation format. This is supportive of Martin (1978) who suggested that both verbal and visual items are located in a store that is susceptible to disruption through the processing, encoding or recalling of nontarget information. However, the nature of the representational codes affect the attentional processes used to manage information, and thus the accessibility of such memory items.

The SIIT was designed as an independent, but complimentary measure of PM capacity. The correlational analysis showed measures of PM capacity from the free recall data and the focal and *k* measures from the interleaved items task were correlated, thus suggesting common cognitive processes underlying both tasks i.e. the active maintenance of information in PM. The comparison of PM capacity estimates from the free recall data highlighted PM capacity was higher in the free recall task than in the interleaved items task, which was consistent across all age groups. This was also the case for Hall et al. (2015) who used three independent measures of PM capacity, which produced three different levels of performance. Nonetheless, all three tasks did show a developmental increase in recall in children aged five- to eight-years, supporting the view that all tasks provided an index of developmental increases in PM capacity.

The correlational analysis questioned whether the SIIT was a sole measure of PM, as the *k* value and focal recall correlated with PM and SM. The results suggest that children's working memory is susceptible to becoming cluttered with irrelevant, nonfocal information, making it harder to recall target information from PM and potentially forcing the use of cue-dependent search processes in SM. The interleaved nature of the SIIT is similar to the procedure of complex span tasks whereby memory items are interleaved with the processing of other information in the environment. Therefore, it may be the case that SM contributed more in longer lists as children reach their capacity and items were displaced into SM due to the maintenance of new, incoming information into PM, supportive of Martin (1978).

This also brings into question whether nonfocal items also correlated with SM, assuming that items were processed and maintained in the first place. This was not the case, as nonfocal recall did not correlate with any of the experimental measures. This supports the dichotic listening literature that states unattended items are recalled from a separate perceptual memory system (Broadbent, 1958; Bryden, 1971), and not transferred to working memory (Cowan et al., 2006). Future research needs to verify whether PM and/or SM are involved in the recall of irrelevant information when performing such tasks. The current task only used a small number of trials to assess nonfocal recall, and thus is may be the case that it affected the profile of nonfocal recall and its relations to other working memory measures.

A key theoretical objective explored in this experiment was to resolve theoretical discrepancies regarding whether developmental capacity increases were evident in both PM and SM. Despite the historical (Cole et al., 1971; Thurm and Glanzer, 1971) and current (De Alwis et al., 2009) literature, the free recall and SIIT have shown the capacity of the immediate memory system increased through childhood. In addition, developmental increases in the ability to allocate attention to target information whilst also ignoring irrelevant information was also evident. Younger children were less efficient in their ability to allocate attention, thus they were less able to exclude unnecessary information from PM, cluttering up working memory. By seven- to eight-years of age, children were able to focus on the high priority information, following the demands of the task. Overall, Experiment 1 has provided insight into the cognitive underpinnings of the development of PM capacity, and its application to Unsworth and Engle's characterisation of PM. To extend their description, the SIIT has provided evidence of how different representational codes of information affect the use of PM, attributed to the attentional processes required to actively manage the information maintained in the capacity limited memory system.

Future work needs to consider whether the distribution of attention across the three presentation formats of the SIIT are equivalent (Cowan et al., 2006), ensuring the visual condition requires equivalent levels of attention as the auditory and dual conditions of the task. The consistencies of the visual findings in the current work and Cowan et al's work, in comparison to the auditory and dual performance may be explained by the nature of how the stimuli were encoded, causing the visual task to resemble a short-term memory task whilst the auditory tasks demonstrates the ability to use selective attention (Hallahan et al., 1974). This is accentuated by the experimental layout and the focal and nonfocal stimuli being presented on different sides of the screen. This gave participants the opportunity to focus on the visual focal items and ignore the visual nonfocal items. However, this was not possible for the auditory and dual conditions as participants heard the stimuli through headphones, making it harder to ignore. To explore this further, Experiment 2 aims to explore how performance changes and attentional distributions are affected when all stimuli are presented in the centre of the screen. This should present a more detailed examination of the specific attentional processes required to actively maintain items in PM.

Chapter 3

The impact of modality on primary memory: a re-design of the serial interleaved items task

3.1 Experiment 2: Introduction

The SIIT task has provided a novel way to explore PM in adults and children. Experiment 1 showed how presentation modality and their respective representational memory codes affected PM capacity. Age-related increases in the number of items held in working memory and the proportion of focal recall was evident. But alongside this finding, auditory memory representations were most affected by children's ability to actively maintain memory representations in the face of distraction. This resulted in lower levels of high priority, focal recall and a higher level of low priority, nonfocal recall. As part of understanding these findings, the ability to allocate attention was considered as described by Unsworth and Engle (2007b). However, these findings may be a consequence of the experimental design causing uneven attentional distributions and different levels of difficulty in the recall of focal or nonfocal items. Experiment 2 was a focused follow up experiment specifically investigating the task design of the SIIT and its impact on the findings of Experiment 1. The experimental layout of the task was modified to ensure that the task required more equivalent levels of attention in both the auditory and visual versions (Cowan et al., 2006).

A key finding of Experiment 1 was how the auditory representation of stimuli affected the dependent measures taken from the SIIT. Focal recall was diminished and nonfocal recall heightened when the stimuli had an auditory component. This suggested that auditory information was impaired for children's recall as they did not have the attentional mechanisms in place to stop the maintenance and recall of such items, therefore cluttering working memory with irrelevant information. However, there is an alternative explanation attributed to the experimental layout of the task. As part of the differentiation of which items were focal and which were nonfocal they appeared on the left and right hand side of the screen respectively (see Figure 2.1 for an illustration). It is possible that part of participants' strategy was to ignore lower priority nonfocal items by not looking at the right hand side of the screen. This meant they would not have to attend and label the irrelevant information, which was not possible when listening to stimuli in the auditory and dual conditions. Therefore, Experiment 2 used the same stimuli and procedure of the SIIT in Experiment 1 but changed the layout so all items appeared in the centre of the screen. The change in experimental layout should also balance the attentional distribution of attention across the two presentation formats (Cowan et al., 2006), in turn equalising the difficulty of the task. The findings of Experiments 1 and 2 can then be compared to determine the generality of the modality differences within PM, and the attentional differences observed, indicating whether PM can be considered as a domain-general system of attentional and basic memory abilities.

As a result of changing where the stimuli appear on the screen it is possible that the attentional strategies used to actively maintain focal items and ignore nonfocal items will also change. Specifically a change from selective attention to divided attention. Divided attention is the ability to attend to two stimulus streams by switching between them as they are presented (Gomes et al., 2000). The reason this is suggested is due to a similar situation in the adult literature. Conway et al. (2001) and Colflesh and Conway (2007) both used dichotic listening tasks in adults, the basis of the SIIT. Both experiments involved participants' listening to a target message, whilst ignoring distractions (which in this case was the participant's name). However, the tasks differed in how participants were instructed to respond. Conway et al. (2001) asked participants if they heard their name listening to the auditory information, whilst Colflesh and Conway (2007) instructed participants to press a button immediately after detecting their name. In the former task, 20% of high-WMC individuals in comparison to 65% of low-WMC individuals reported hearing their name in the irrelevant message. The latter experiment showed the opposite, whereby 66.7% of high-WMC individuals and 34.5% of low-span individuals heard their name. The difference in results was accounted for by stating that those with a higher WMC were better at adjusting their focus of attention according to the task goals (Colflesh & Conway, 2007). It may be the case that by changing the task design a similar situation may emerge. By looking at this in adults and children, it may be possible to support the adult findings of Conway et al. (2001) and Colflesh and Conway (2007), but also provide a developmental perspective on how children adjust their attentional strategies to help the active maintenance and management of immediate information.

Taking on board the new experimental layout, modality-specific versions of the task were also tested to further investigate how the auditory and visual modes of presentation were managed within PM. Participants had to recall focal items in one modality, whilst non-focal information was in a different modality (i.e. participants experienced focal auditory items and nonfocal visual items and vice versa). The aim of this was to settle the contradictory findings of Experiment 1 as to whether the traditional modality effect (the greater recall of auditory information in comparison to visual information from an immediate memory system) is evident within this independent PM task in adults and children. The creation of modality-specific versions of the task will help separate the advantages of auditory information in focal recall (believed to be recalled from PM), but also its disadvantages in terms of resisting its presence in output. Visual information on the other hand should remain relatively constant with the results found in Experiment 1, due to performance being more dependent on a verbal labelling effect as opposed to efficient attentional distribution.

The aim of Experiment 2 was to replicate the correlations between WMC, *k* and focal recall, which would indicate a cognitive commonality of the ability to actively maintain memory representations in PM, as part of WMC. However, the question still remains as to whether nonfocal items are processed and recalled from working memory. In Experiment 1, the non-significant correlations between nonfocal recall and all other memory measures indicated participants did not process nonfocal items, and therefore they were not transferred into working memory (Cowan et al., 2006). This was considered to be a consequence of the selective nature of the task. The placement of stimuli in the centre of the screen provides a higher probability of participants processing all items. This in turn may change the inter-relations between nonfocal recall and WMC.

Overall, Experiment 2 used two versions of the SIIT. The modified SIIT focused on the experimental layout and its impact on the attentional management and recall of items of different modes of representation within PM. Therefore, by positioning all stimuli in the centre of the screen, there were two potential outcomes. Firstly, the modality effects would no longer exist, suggestive of a domain-general system. Alternatively, the modality differences may still be evident and therefore domain-specific capacities and processes need to be considered as part of the characterisation of PM. The comparison of the data from Experiment 1 and the current experiment will help decipher which account is most accurate. The second, modality-specific version of the task provides the assessment of how auditory and visual information differ in their ability to enhance but also hinder the recall of items maintained in working memory. To further enhance the strength of the data, Experiment 2 was made into a within-subjects design. This should provide more confidence that the observed effects are not confounded by any group effects. Therefore, two sets of participants were used. The first set all took part in the modified version of the SIIT, whilst the second set all took part in the modality-specific SIIT. This enabled the direct comparison of how the different modality representations affected their performance within the new versions of the SIIT.

3.2 Method

3.2.1 Participants

In total 79 participants took part in the experiment (see Table 3.1). The same age groups were used as in Experiment 1: five- to six-year olds (Year 1: N = 39; M = 6:02 years; range: 5:06-6:11 years), and seven- to eight-year olds (Year 3: N = 40; M = 7:08 years; range: 7:00-8:04 years) and adults (N = 30; M = 19.02 years; range: 18:06 - 20:08 years, 22 female). Participants were separated into two groups: Those who took part in the original modified SIIT and those who took part in the modality specific SIIT.

Table 3.1: The mean age of participants in Experiment 2 in the modified and the modality-specific serial interleaved items tasks (SIITs).

	Year 1		Year 3		Adults	
	N	*M*	*N*	*M*	*N*	*M*
Modified interleaved items task	19	6:03	20	7:09	10	19:02
Modality-specific interleaved items task	20	6:03	20	7:08	20	19:03

3.2.2 Materials

All stimuli were taken from the stimulus pool in Experiment 1. One hundred and eighty-seven stimuli were chosen, half of which were pictures also taken from the same stimulus pool. This accommodated for both the auditory and visual versions of the task. The same stimuli were used in the modified and modality-specific SIITs.

3.2.3 Design and Procedure

Participants were tested on two tasks: a listening span task and one of the versions of the SIITs. Each version of the interleaved items task followed a within-subjects design. Participants took part in both the visual and auditory versions of the task. The tasks were presented in one session lasting approximately 25 minutes. The order of tasks within the session was counterbalanced across participants. All tasks were developed on PsychoPy (Pierce, 2007, 2009) carried out on a Macbook Laptop.

3.2.4 Serial interleaved items task (SIIT)

All of the versions of this task used both auditory and visual presentation modalities. The modified interleaved items task followed the same procedure as Experiment 1 (section 2.2.5), but the position of the characters and stimuli were modified. Instead of the focal and nonfocal characters being on the left and right hand side of the screen respectively, they were all presented in the centre of the screen.

The modality-specific version of the task used different modalities for the focal and nonfocal stimuli. Participants were presented with auditory focal items and visual nonfocal items, and vice versa. The position of stimuli within the task was the same as the modified interleaved items task, all placed in the centre of the screen.

3.2.5 Listening span task.

A different listening span task was used in the current experiment to Experiment 1. It was changed to a sentence completion task based on the work by Towse et al. (1998b). The task required participants to listen to a series of sentences and generate the final missing word (e.g. A baby cat is called a ?). Once all the sentences were completed participants were instructed to recall the target words in serial order. Four blocks of trials were included with three trials in each block creating a total of 12 trials. The number of sentences within a single trial ranged from two to five, a total of 42 sentence stimuli. The list lengths were presented sequentially.

The listening span task was changed from the original span task used in Experiment 1. It was decided that the focus between the processing and storage elements in the previous listening span task was not balanced. Participants had to make a judgment within the processing element of the task (is this sentence silly?), which seemed to be the main focus for children, taking away the value of the storage items. Therefore, a sentence completion task was thought to be more appropriate as the storage item played a more active role in the task itself. Participants had to generate the storage item themselves as part processing, but then also had to recall the same item at the end of the trial, reflecting storage.

3.3 Results

3.3.1 The modified serial interleaved items task (SIIT)

To follow on from Experiment 1, the same three measures were used: proportion of focal and nonfocal recall and a *k* value (number of items held in working memory). To analyse this a series of 2 (modality: auditory vs. visual) x 3 (age: Year 1 vs. Year 3 vs. Adults) mixed factor ANOVAs were carried out. Age-related and presentation modality differences were analysed using posthoc tests and multiple pairwise comparisons using a Bonferroni correction.

Descriptive statistics are presented in Table 3.2.

Table 3.2: Descriptive statistics of three experimental measures as a function of experiment version, presentation modality and age (one standard error).

	Focal recall		Nonfocal recall		k	
	Expt 1	Expt 2	Expt 1	Expt 2	Expt 1	Expt 2
Year 1						
Auditory	.65 (.047)	.52 (.041)	.39 (.062)	.29 (.053)	1.38 (.114)	.98 (.098)
Visual	.89 (.049)	.52 (.041)	.16 (.064)	.37 (.053)	1.12 (.119)	.79 (.098)
Year 3						
Auditory	.74 (.049)	.63 (.040)	.28 (.064)	.45 (.052)	1.75 (.119)	1.47 (.096)
Visual	.87 (.049)	.57 (.040)	.28 (.064)	.40 (.052)	1.34 (.119)	.97 (.096)
Adults						
Auditory	.91 (.051)	.75 (.056)	.65 (.067)	.78 (.073)	2.37 (.124)	1.90 (.135)
Visual	.95 (.046)	.79 (.056)	.51 (.060)	.64 (.073)	2.23 (.110)	1.75 (.135)

The current experiment demonstrated an age-related increase in the proportion of focal recall, $F(2,46) = 5.635$, $p = .006$, $\eta p^2 = .197$, however, there was no difference in the auditory and visual focal recall, $F(1,46) = .050$, $p = .823$, $\eta p^2 = .001$. A non-significant interaction with age, $F(2,46) = .666$, $p = .518$, $\eta p^2 = .028$, indicated that all age groups showed a similar pattern of focal recall as a function of modality.

The only significant effect in the proportion of nonfocal recall was an age-related increase in performance, $F(2,46) = 7.224$, $p = .002$, $\eta p^2 = .239$. Year 1 recalled fewer nonfocal items than both Year 3 and adults (both $ps < .05$), whilst the two latter groups produced equivalent levels of nonfocal recall ($p = 1.000$). The presentation format did not impact nonfocal recall, $F(1,46) = 1.610$, $p = .211$, $\eta p^2 = .034$, which was similar across all groups, reflected in the non-significant interaction, $F(2,46) = 1.676$, $p = .198$, $\eta p^2 = .068$.

Age-related increases in k were also evident, $F(2,46) = 14.889$, $p < .001$, $\eta p^2 = .393$. Years 1 and 3 produced similar levels of k ($p = .063$), both of which were smaller than the adults k value (both $ps < .01$). The auditory k value was larger than the visual value, $F(1,46) = 22.507$, $p < .001$, $\eta p^2 = .329$, but this factor interacted with age, $F(2,46) = 4.057$, $p = .024$, $\eta p^2 = .150$. Year 3 were the only age groups to show the modality effect described, $F(1,19) = 25.538$, $p < .001$, $\eta p^2 = .573$. The same effect in Year 1 and adults were approaching significance (Year 1: $F(1,18) = 4.116$, $p = .058$, $\eta p^2 = .186$; Adults: $F(1,9) = 5.000$, $p = .052$, $\eta p^2 = .357$)

The results from the current experiment were then compared to the original SIIT from Experiment 1 in a series of 2 (experiment version: Experiment 1 vs. Experiment 2) x 2 (presentation modality: auditory vs. visual) x 3 (age: Year 1 vs. Year 3 vs. Adults) mixed factor ANOVAs. The two different experiments produced different levels of recall across the three measures. The proportion of focal recall and k values extracted from Experiment 1 were higher than the same measures produced in Experiment 2 (focal recall: $F(1,166) = 56.548$, $p < .001$, $\eta p^2 = .254$; k: $F(1,166) = 34.580$, $p < .001$, $\eta p^2 = .172$). In contrast, higher levels of nonfocal recall were evident in Experiment 2 in comparison to Experiment 1, $F(1,177) = 9.398$, $p = .003$, $\eta p^2 = .054$.

A significant interaction between experiment version and presentation modality was evident, $F(1,166) = 6.357$, $p = .013$, $\eta p^2 = .037$. The original SIIT from Experiment 1 produced a higher level of visual focal recall than the auditory focal recall, $F(1,74) = 30.485$, $p < .001$, $\eta p^2 = .292$. This was in contrast to the current experiment whereby the proportion of auditory focal recall and visual focal recall was at a similar level, as described above. The difference in nonfocal recall across the two experiments was also reflected in a significant interaction between experiment and modality, $F(1,166) = 4.214$, $p = .042$, $\eta p^2 = .025$. Whilst Experiment 1 showed auditory recall to be significantly larger than the nonfocal visual recall, Experiment 2 showed equivalent levels of nonfocal recall across the two modalities. The *k* value demonstrated increased auditory recall in both experiments despite the change in experimental layout, $F(1,166) = 17.200$, $p < .001$, $\eta p^2 = .094$. This was consistent across the three age groups and the different experiment versions, indicated by non-significant interactions between all factors (all *ps* > .05).

3.3.2 Modality-specific effects within the serial interleaved items task (SIIT)

In order to further examine modality-specific characteristics of memory representations, the three dependent measures (*k*, proportion of focal and proportion of nonfocal recall) from the two versions of the SIIT from Experiment 2 were compared. This provided a further understanding of how high- and low-priority memory representations of different presentation formats are maintained in a highly accessible state in working memory. All analyses were carried out in 4 (task version: auditory modified vs. auditory modality-specific vs. visual modified vs. visual modality-specific) x 3 (age: Year 1 vs. Year 3 vs. Adults) mixed factor ANOVAs. All comparisons of age, presentation modality and task versions were analysed using posthoc tests with a Bonferroni correction.

The proportion of focal recall showed the expected age-related increase, $F(2,206) = 11.699$, $p < .001$, $\eta p^2 = .102$, with developmental increases across each age group (all *ps* < 05). A significant effect of task version, $F(3,206) = 25.696$, $p < .001$, $\eta p^2 = .272$, showed the auditory and visual modality-specific tasks generated higher levels of focal recall than the two modified versions (all *ps* < 001). Within the modality-specific tasks, the auditory version produced a higher proportion of focal recall than the visual task ($p < .001$). As previously established in section 3.3.1, there were no differences between the auditory and visual modified versions of the task (p = 1.000).

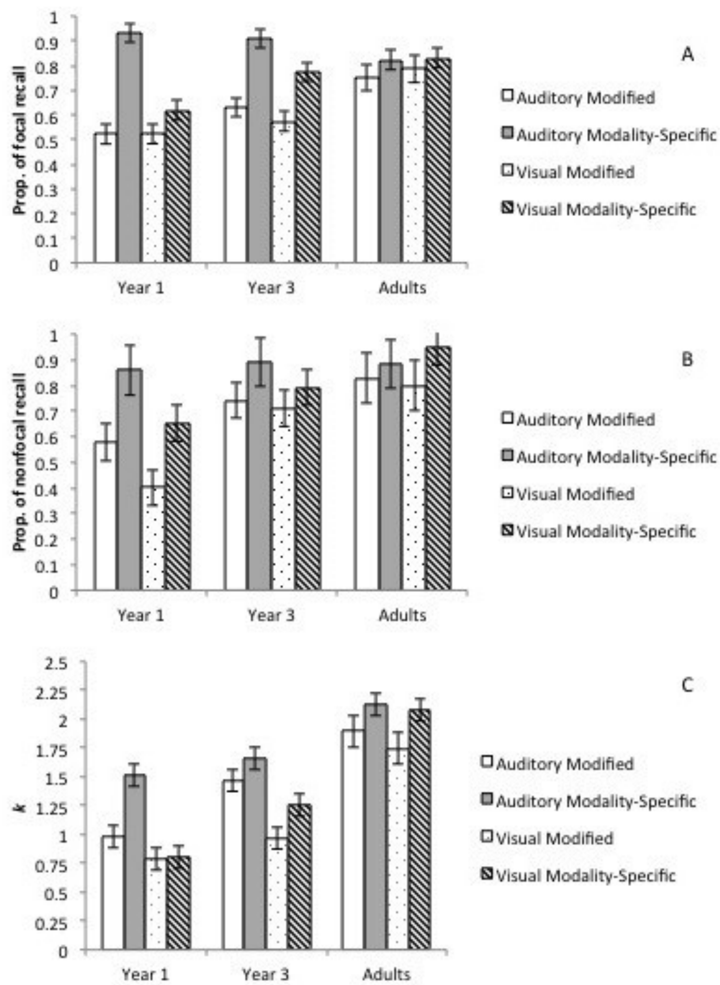

Figure 3.1: The significant interaction between task version and age as a function of focal recall (A); nonfocal recall (B); and items held in working memory (C). Error bars represent one standard error from the mean.

A significant interaction between age and task version showed children performed in a similar manner to the main effect, $F(6,206) = 4.938$, $p < .001$, $\eta p^2 = .126$ (see Figure 3.1A). Year 1 produced a significantly higher proportion of focal recall in the auditory modality-specific task in comparison to the other three tasks that did not differ from each other (all *ps* < .001). Year 3 children also produced a significantly larger proportion of focal recall in the auditory modality-specific task (all *ps* < .001), followed by the visual modality-specific task that produced higher levels of recall than the two modified versions of the task (all *ps* $< .01$). In contrast, the adults' performance did not vary as a function of task version, $F(3,59) = .432$, $p = .731$, $\eta p^2 = .023$

The proportion of nonfocal recall showed the age-related increase in this measure, $F(2,206) = 10.523$, $p < .001$, $\eta p^2 = .093$. Year 1 produced the lowest level of nonfocal recall in comparison to Year 3 and adults (all *ps* < 05), however, Year 3 and adults performed at an equivalent level ($p = .421$). In terms of task version, $F(3,206) = 6.388$, $p < .001$, $\eta p^2 = .085$, the nonfocal auditory recall within both versions of the SIIT was higher than the visual versions (Figure 3.1B). Both modality-specific versions of the tasks produced larger proportions of nonfocal recall in comparison to the corresponding modified versions of the tasks (auditory modified vs. auditory modality-specific: $p = .004$; visual modified vs. visual modality-specific: $p = .047$). The non-significant interaction between the two factors, $F(6,206) = .983$, $p = .438$, $\eta p^2 = .028$, highlighted that all age groups reacted in a similar fashion.

Systematic age-related increases in the k value was again evident, $F(2,206) = 74.209$, $p < .001$, $\eta p^2 = .419$. A significant effect of task version, $F(3,206) = 16.965$, $p < .001$, $\eta p^2 = .198$, revealed the modality-specific auditory task generated the highest k value in comparison to all task versions (all *ps* $< .05$), whilst the modified visual version of the task produced the lowest level of recall (all *ps* $< .05$). The interaction between the two factors, $F(6,206) = 2.549$, $p = .021$, $\eta p^2 = .069$, highlighted differential performance profiles across the ages (Figure 3.1C). Both sets of children demonstrated an effect of task version (Year 1: $F(3,77) = 12.872$, $p < .001$, $\eta p^2 = .343$; Year 3: $F(3,79) = 11.561$, $p < .001$, $\eta p^2 = .313$). Children in Year 1 produced the highest level of recall in the auditory modality-specific version in comparison to the three other tasks (all *ps* $< .001$), but the two visual tasks did not differ from each other ($p = 1.000$). Within Year 3, both auditory tasks generated a higher recall than the visual tasks (all *ps* $< .05$). However, the number of items recalled did not differ within the auditory tasks (p = .837), which was the same within the visual tasks (p = .141). Finally, the adults did not show any differences in recall performance across the four tasks, $F(3,59)$ = 1.520, p = .219, ηp^2 = .075.

3.3.3 The inter-relations between WMC, and measures from the serial inter-leaved items task (SIIT)

Table 3.3 reports the zero-order correlations of the modified SIIT tasks and the WMC, indexed by a listening span task. Age was also partialled out to determine any general age-related effects influencing the correlations. Significant positive correlations were evident between all measures. The one exception was the non-significant correlation between nonfocal recall and WMC.

Table 3.3: The correlational analysis between all experimental measures. The lower triangle reports the partial correlations controlling for age.

-	1.	2.	3.	4.
1. *k*	-	.918***	.583***	.617***
2. FR	.879***	-	.496***	.595***
3. NFR	.420***	.284**	-	.489***
4. WMC	.339***	.245*	.155	-

Note. *k* = Items held in working memory; FR = Focal Recall; NFR = Nonfocal Recall; WMC = Working Memory Capacity.

$p < .05$*; $p < .01$**; $p < .001$***

3.4 Discussion

The experimental design of the SIIT was altered to balance the attentional distributions and difficulty of the task. By taking this into consideration, a more detailed understanding of the cognitive profile of PM was provided in regards to capacity as well as the attentional mechanisms that underlie the cognitive construct. The comparison of the original version of the task in Experiment 1, and the modified SIIT in Experiment 2 showed consistencies in the age-related increases in the number of items held in working memory, providing further evidence of an increase in WMC across the age range five- to eight-years. As with Experiment 1, the modified version of the task still demonstrated increases in the proportion of focal and nonfocal recall, between adults and children, providing further support for the argument that PM capacity does increase with age.

By changing where stimuli were presented within the SIIT design, it provided the opportunity to determine whether performance across the two modalities provided indications of whether PM is domain-specific. The results from Experiment 1 indicated that the visual version of the task might act as a short-term memory task whilst the auditory version required an effective allocation of attention in order to be successful. Participants found it easier to recall higher priority visual information and very difficult to not recall nonfocal auditory information. To eliminate task differences as an alternative explanation, stimuli were presented in the centre of the screen. In contrast to Experiment 1, participants were no longer able to select which visual focal items were verbally labelled with no distraction from visual nonfocal items. Therefore, optimum performance on both auditory and visual versions of the SIIT required participants to distribute their attention in a similar manner; actively maintaining immediate memory items in the face of distraction. This was supported by the proportion of auditory and visual focal recall being at similar levels. Interestingly the level of nonfocal recall across the two modalities was also at an equivalent level, which differed from Experiment 1 whereby auditory nonfocal recall was higher than visual nonfocal recall. The attentional control necessary to actively maintain PM items applies to both modalities and their corresponding memory representations.

The only modality effect that was evident was the number of items held in working memory, which was larger in the auditory condition. This suggests that when given the opportunity, auditory items have a greater accessibility to working memory than visual items (Salamé & Baddeley, 1982). This does not seem surprising considering the translation of a visual image into a phonological code is a more demanding process than the recall of information already in the appropriate format for recall. However, the ability to recall equivalent levels of focal and nonfocal items suggest PM acts as a domain-general mechanism that allocates attention to new verbal and visual information, both of which are susceptible to incoming interference from new, incoming memory items.

The results from the experiment also indicated a change in attentional strategy. Previously it was believed that adults and children had to select which items were actively maintained. In the current experiment, the results indicated a divided attention strategy. One reason to believe that participants were dividing their attention between the two sources of information as opposed to being selective was the developmental increase in nonfocal recall in Experiment 2, in comparison to the developmental decrease in Experiment 1. The change in attentional strategy was further supported by the correlational data reported in this experiment. Specifically, the non-significant negative correlation between focal and nonfocal recall in Experiment 1 (-.086) shifted to a significant positive correlation in Experiment 2 (.284). This suggests individuals who were able to recall more focal items were also able to recall more nonfocal items, suggesting an ability to successfully divide their attention between the two streams of information, despite their differing levels of priority.

The difference in results as a function of experimental design resonates with the findings of Colflesh and Conway (2007) and Conway et al. (2001), who both used dichotic listening tasks, with subtle differences in the experimental design. Conway et al. (2001) stated that a complex span task was a divided attention task whilst the dichotic listening task was a selective attention task. However, the positive correlation between the complex span and the dichotic listening task measures led Conway et al. (2001) to conclude that working memory enables participants to perform well on both tasks. Colflesh and Conway (2007) explored this further, except participants had to divide their attention between the attended and unattended information. Individuals with a higher WMC were better at dividing their attention than those with lower WMC. Based on this statement, this overlaps with the positive correlation between FR, *k* and WMC. Those individuals who were more proficient at dividing their attention were able to hold more items in WMC, and recall a higher proportion of focal recall, regardless of age. Despite being in the adult literature the work by Colflesh and Conway (2007) and Conway et al. (2001) converges with the children's results in the current experiment. Regardless of the change in attentional strategy, both require control of attention (Engle et al., 1999), which is an integral component of working memory and necessary in complex span and dichotic listening tasks (Conway et al., 2001).

The modality-specific version of the task enabled the opportunity to examine the focal and nonfocal recall of auditory and visual recall without the potential disruption from irrelevant information of the same modality. This provided another opportunity to understand the maintenance of target information of different modalities. In order to do this, the modified and modality-specific SIITs were compared. Focal recall and *k* values produced the systematic age-related increases that had been evident in Experiment 1. Consistent with the modified version of the task, an age-related increase in nonfocal recall was also evident, to the extent that Year 3 and adults recalled a similar proportion of this measure. The modality-specific SIIT made clear distinctions between focal and nonfocal recall due to using two different modalities for the two streams of information. It is possible that this made it easier for participants to distinguish which items were focal and nonfocal recall. Consequently, the modality differences provided a cue as to which type of information needed to be recalled, as opposed to having to use attentional selectivity to retain and recall target information.

The comparison of the modified and modality-specific versions of the task demonstrated a series of differences, indicating the accessibility of memory items of different representations. Within the modality-specific versions, auditory focal and nonfocal recall and the number of items held in working memory were significantly larger than the visual focal recall. This was additional evidence of the sheer accessibility of auditory information and it's accessibility to the cognitive system (Salamé & Baddeley, 1982). The act of verbally labelling visual pictures and subsequently recalling items verbally is a more demanding process than just retaining auditory information in its presentation form and unloading it from immediate memory. However, such accessibility to auditory memory representations also makes them a potential hinderance to the cognitive system, cluttering working memory with irrelevant information, and confusing which items need to be recalled.

The correlational evidence presented in the current experiment for measures between focal recall, items held in working memory (k) and WMC converge with the same correlational evidence presented in Experiment 1. Individuals that were able to maintain memory items and keep them in an accessible state in the face of distraction also demonstrated a higher WMC. Thus, active maintenance of information in an immediate memory system is linked to higher WMC. These findings are consistent with the observations of the serial interleaved lists task by Hall et al. (2015), but are also in line with the description of PM and its contribution to individual differences in adult WMC within the dual-memory framework (Unsworth & Engle, 2007b).

In the current experiment, nonfocal recall also positively correlated with *k* and focal recall, which was not the case in Experiment 1. Individuals who were able to hold more items in working memory were able to recall more focal and nonfocal items when instructed to do so. This further suggests that nonfocal items are being processed and maintained and not held in a perceptual memory system as suggested in Experiment 1. The next question is whether all items are being held in PM or whether some are displaced and retrieved from SM. However, PM and SM estimates were not collected for the current dataset, and therefore it cannot be confirmed. It is worth noting though that the previous correlational analysis in Experiment 1 did show both memory systems were involved in the number of items held in working memory and their proportion of focal recall. As the current experiment has provided supporting evidence that nonfocal recall items are processed, future work could combine the free recall and modified SIIT to determine whether nonfocal recall is also recalled from PM and SM. This would help disentangle the management of highly accessible information from PM and the search processes necessary for more diverse, less accessible memory representations.

There was a positive, albeit non-significant, correlation between nonfocal recall and WMC. This positive relationship was expected based on the divided attentional strategy, however it was non-significant when age was controlled for. Due to its correlations with the other two measures from the SIIT, it does not seem appropriate to continue to suggest that these particular items were held in a perceptual memory system and did not make their way to WMC. Therefore, a potential explanation and a future direction for this experiment is to collect more data points, to increase the power, and enhance the relationship between the two measures. This would provide a clearer result of whether the recall of nonfocal recall is linked to individual differences in WMC.

Overall, Experiment 2 has shown that developmental increases in WMC are accompanied by developmental increases in the number of items children maintain in working memory, but also their ability to allocate attention effectively to high-priority information. In addition, the experiment has reported more detailed evidence of how items of different presentation modalities, are actively retained, managed and recalled within working memory. The modified experimental design has shown that the recall of visual and auditory information is equivalent when the attentional distribution of the tasks is more balanced. However, auditory information still holds an element of accessibility that visual items do not. The developmental change in PM was further confirmed. Developmental increases were evident in regards to the number of items children could hold in working memory. But also, developmental change in the ability to allocate attention was also evident, indicative of developmental changes in the control of attention. Despite potential changes in attentional strategy, the younger children showed a lesser ability to allocate attention efficiently. If the attentional mechanisms are not fully developed it can clutter working memory with irrelevant information. Therefore, the chapter has shown the need for attentional control as part of the underlying mechanisms that support the basic memory abilities of the efficient running of the PM system.

Chapter 4

Probed recall, presentation modality and the accessibility of memory items in secondary memory

4.1 Experiment 3: Introduction

Free recall has been used as a tool to investigate the combined contributions of the active maintenance of memory items in conscious awareness and search and retrieval processes from a longer-term store. The free recall task in Experiment 1 revealed children's serial position curves incorporated predominant recency effects but very little primacy. This is in contrast to adults who showed both types of effects. This implied as part of development, children rely on the output of immediate information; they find it very difficult to strategically search and retrieve memory representations outside of immediate focus. This deficiency was the focus of the current experiment. Returning to a free recall context, Experiment 3 investigated whether children could actually access primacy items when instructed to, indicating that primacy items are still accessible to children despite not appearing in recall.

The idea of presentation modality affecting the accessibility of memory representations is also still of interest. The SIIT - the paradigm introduced earlier whereby the list is split into two sources with different priorities - showed that the management of different memory codes contributed to an individual's ability to select, ignore and process information from the environment in the face of distraction. However, this was only in an immediate setting. There is also a possibility that memory representations of different formats could also influence their accessibility from SM. This was a second interest of this experiment; whether the accessibility of items unloaded from immediate memory or retrieved from a longer-term store is affected by the format of the to be remembered memory items.

In the current experiment, auditory and visual free recall tasks were administered to investigate how presentation modality affects the two different processes that underlie the dual-memory framework. The modality effect should be evident within the recency section of a serial position curve (e.g. Craik, 1969; Murdock & Walker, 1969; Watkins, 1972), manifesting an auditory advantage in the recall of final list items. Based on children's ability to hold more auditory items in working memory in all versions of the SIIT, it is possible that children will also produce more accurate auditory recall for final list items in comparison to the visual condition. In contrast though, the dual-store models argue that due to PM being a unitary store, modality is irrelevant (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965). According to this view, individuals should recall equivalent levels of auditory and visual items from PM.

Children's memory for pictures also needs to be considered as it has been found that children are better at remembering pictures than words (Bernbach, 1967; Cole et al., 1971; Siegel & Allik, 1973; Spitzer, 1976). In addition, previous adult literature has shown the recall of visual items at the beginning of a list are better remembered than auditory items in the same positions (Beaman, 2002; Madigan, 1971; Metcalfe & Sharpe, 1985). Within the current thesis, the SIIT in Experiment 1 did show a visual advantage in focal recall, attributed to their ability to retain both auditory and visual memory representations. To investigate this, serial position curves and estimates of PM and SM will be extracted from the Tulving and Colotla formula to determine memory system differences as a function of presentation modality. Together, this should provide the potential for two modality effects to be evident based on the accessibility of different types of memory representations: enhanced auditory recall within the recency section, but enhanced visual recall in the primacy section of a list.

An alternative experimental design was implemented in order to further explore the accessibility of items in the beginning and middle of free recall lists: the probed split span task. This task combined the use of three recall probes and the two modalities. Participants were given three different recall probes after the presentation of a list: recall items from the beginning of a list (first segment recall probe), recall items from the end of a list (second segment recall probe) or recall what you can remember (full list recall probe). As evidenced in section 2.3.1, children found it very hard to recall items from the beginning and middle of a free recall list. Despite the use of manipulations designed to affect primacy recall (list length and presentation rate), children aged five- to eight-years predominantly began their recall with the final list items and subsequently outputted the last items presented in a list. By changing the focus and forcing participants to recall either primacy or recency items they will have to apply mechanisms necessary for efficient retrieval from SM plus the active maintenance of items in PM. In order to be successful, participants will have to try and distribute their attention to all items across a list. This limits the possibility that children choose to remember the last few items, regardless of whether they were able to recall primacy items or not. Based on this, it provides the opportunity to investigate whether children do have access to earlier list items, reflective of SM. This will be evidenced in the extent to which primacy effects are elevated when participants are given a first segment recall probe in comparison to the full list probe. In addition, any developmental differences in children's ability to use the first section recall probe will act as a demonstration of their flexibility in recall strategy, but also that they have access to memory representations from the beginning of a list, indicative of retrieval from SM.

The use of recall probes for different sections of the memory list may change the serial position curves observed. The extent to which primacy and recency effects are evident vary as a function of recall instruction, probes and cues (e.g. Bjork & Whitten 1974; Dalezman 1976; Katz 1968). Unsworth et al. (2011) showed participants who began their recall with primacy items produced an enhanced primacy effect, with a diminished recency effect, whilst this was the opposite when participants began their recall with a recency item. It is possible that serial position functions will differ as a function of the recall probe. The first segment probe should produce enhanced primacy recall, the second segment probe should produce enhanced recency recall. However, it will be interesting to observe what the full list probe generates. There are two potential outcomes: participants will generate a serial position curve similar to their natural recall strategy, or they will produce a relatively stable level of performance across all serial positions with no elevation at either the beginning or end of a list. This is suggested on the assumption that participants will have to distribute their attention across the whole list in order to be able to generate the target items based on the recall instruction given.

The ten-item lists used in the probed split span task were partitioned into auditory and visual segments. Therefore, participants could be presented with a first segment that was visual and a second segment that was auditory or vice versa (see figure 4.1 in section 4.2.5). It is predicted that the auditory second segments (i.e. the recency effect) should produce more accurate recall than when the same segment is visual, based on the adult free recall literature (Craik, 1969; Murdock & Walker, 1969; Watkins, 1972) and the SIIT findings. Differences in the retention of auditory and visual memory items can be related to the domain-specific storage systems described in the multicomponent model (Baddeley & Hitch, 1974): the phonological loop and the visuospatial sketchpad. It is established that the amount of information retained in the phonological store increases from two- or three-items at the age of four-years, to six- to seven-items by early adulthood (Hulme et al., 1984). Therefore, the basic storage elements are evident from three-years old (Gathercole & Adams, 1993). However, the ability to actively rehearse the contents of the phonological store does not appear until about seven-years of age (Flavell et al., 1966; Gathercole et al., 1994). Without this, phonological information is susceptible to decay and being lost from memory. Thus, despite its ready availability, if auditory information is not rehearsed and actively maintained it will not be consolidated into the more durable, longer-term store. In comparison, the presentation of visual pictures produces a memory representation of the image itself, but also retained in phonological memory due to the vocal labelling of the image. This means it is potentially at an advantage due to its dual retention in working memory.

There is potential for a visual primacy advantage based on the retention and durability of the memory representation. Work by Beaman and colleagues have put forward the concept of an inverted modality effect (Beaman, 2002; Beaman & Morton, 2000), whereby a visual advantage in the primacy section of a list is evident in comparison to the auditory primacy section. Therefore, within the split span task, it would mean elevated recall of the first segment of a list when it is visual compared to when it is auditory. The assumption follows that when individuals are cued to recall recency items, performance should be at ceiling for both modalities (Craik, 1969). Subsequently, the second part of recall required remembering primacy items, whereby visual recall is greater than auditory recall. This was assessed by Beaman and Morton (2000) using free recall, and Beaman (2002) and Cowan et al. (2002) using serial recall. To my knowledge, the inverted modality effect has not been investigated in children. Therefore, in trials when participants are instructed to recall the second segment first, the extent to which they can recall auditory and visual items from the first segment afterwards will be compared. This will be used as an index of the robustness of memory representations and their accessibility for recall.

Output interference refers to the negative impact of an item's recall on the subsequent production of others. In other words, recalling the last item first, makes the recall of the second-to-last items harder, and in turn, both of these items would impair the recall of another (Whitten, 1978). Raymond (1969) interpreted output interference in terms of how it affects PM and SM. The probing of memory items from a specific section of a list, results in the output interference from that set recalled, and therefore, all subsequently probed items are recalled from SM. Linked with the inverted modality effect, it is questionable whether the effect is an issue in regards to the extent to which one memory representation is more fragile than another, and thus less accessible outside its active maintenance. This experiment examines whether the auditory modality exhibits the profile of a greater availability when unloaded immediately after presentations, yet a distinct vulnerability when other items are recalled first. In contrast, the recall of visual memoranda should be relatively invariant to this type of interference.

It should also be acknowledged that recalling primacy items does not definitely mean participants are retrieving memory representations from SM. Participants could be actively maintaining the first items presented to them and forgetting the rest of the list (Jarrold et al., 2015). If this is the case then potentially we should see two recency effects, one for each section, indicating the use of two domain-specific immediate memory constructs. Additionally, due to the split nature of the task, it is possible that two primacy effects within each section will also be observable. This would suggest that each section is held in separate auditory and visual PM and SM systems, lending support for Shah and Miyake's functional architecture of domain-specificity within working memory. Alternatively, participants may only exhibit one primacy and recency effect dependent on the recall probe provided, bringing back the argument of domain-general PM and SM systems that processes both types of information regardless of its modality.

Experiment 3 had three clear themes. First, in line with the series of free recall tasks, presentation modality was manipulated. Analyses of serial position effects demonstrated any differences in the serial position curves as a consequence of this manipulation whilst the implementation of Tulving and Colotla (1970)'s method examined whether the modality effect was evident in the recall of PM items. Second, the split span task was administered to explore whether children were able to step away from their default recency output strategy and demonstrate an accessibility of primacy items, reflective of retrieval from SM. Finally, presentation modality was used to partition free recall lists within the split span task to determine the extent to which auditory and visual memory representations differ in accessibility. This was investigated by comparing the recall of auditory and visual items in the primacy and recency sections. An additional dimension to examine the robustness of the different memory representations was to examine whether an inverted modality effect was present, an indication of how different kinds of memory representations are managed and their susceptibility to output interference.

4.2 Method

4.2.1 Participants

Parental consent was gained for 145 children in Year 1 (five- to six-year olds, N = 49, M = 6:00 years, range: 5:05 - 6:07 years, 27 female); Year 3 (seven- to eight-year olds, N = 43, M = 8.00 years, range: 7:02 - 8:06 years, 21 female) and Year 5 (nine- to ten-year olds, N = 53, M = 10.00 years, range: 9:02 - 10:07 years, 34 female). Forty-five undergraduate students were recruited from Lancaster University (M = 20.08 years, range: 18:02-29:05 years, 35 female), all of whom gave full consent to undertake the study.

4.2.2 Materials

A corpus of 466 words were used, increasing the stimulus pool used in Experiments 1 and 2, but maintaining the strict selection process (see section 2.2.2). Half of the stimuli were randomly assigned to be visual stimuli and converted into coloured pictures taken from Hall et al. (2015). The other half of the stimulus pool were auditory stimuli recorded in a male voice. All recordings lasted 750ms, followed by an ISI of 250ms. Stimuli were then randomly assigned to lists for recall. The free recall and probed split span tasks were programmed in PsychoPy (Pierce, 2007, 2009) on a 15-inch MacBook laptop.

4.2.3 Design and Procedure

Research sessions involved individual testing that lasted 40 minutes. The children's testing sessions took place in a quiet classroom setting, whilst the adults were tested in a laboratory setting in the Psychology Department, Lancaster University. All participants completed the free recall task and the probed split span task in one session following a within-subjects design. The free recall task incorporated two types of list: auditory lists participants had to listen to and visual lists that participants had to look at on a computer screen. The probed split span task contained four blocks to reflect the four different types of recall lists used in this task. The order of the four blocks was counterbalanced across participants. In addition, participants either began or ended the session with the free recall task.

4.2.4 Free recall

This task followed a similar procedure to Experiment 1, but in this case presentation modality was manipulated. Participants completed a total of six trials broken down into three auditory lists and three visual lists. It was decided to use ten-item lists based on the Experiment 1 findings (section 2.3.4) in which all age groups were able to produce primacy effects, but developmental differences were evident in the size of the effect. Within the auditory condition, participants heard the list items in a female voice, whilst for the visual condition participants watched the visual stimuli on the screen. Once the presentation of a list finished, participants were asked to recall all the items they could remember in any order. The serial position and order of correct recall were recorded.

4.2.5 The probed split span task

This was a free recall task that consisted of 42 trials with a list length of ten-items per trial. The trials were manipulated by presentation modality and recall probe (see Figure 4.1). The task included four blocks of trials that consisted of nine trials in each block.

Presentation modality was used as a means to partition or split the list in a way that was clear to the participants. As a result, the list contained first and second segments, the recall of which could be cued in turn. The partitioning of both first and second segments differed within each block, generating a “short” segment that comprised four items and a “long” segment that comprised six items. For simplicity, the different blocks will be referred to by their modality composition (for example, block 1 will be referred to as 4V-6A, corresponding to four visual items and six auditory items, see Figure 4.1). The use of a short four-item section should demonstrate a relatively stable level of performance with no elevation at the beginning and end of the section. In contrast, the long six-item section should demonstrate elevated recall of beginning and end items of a section from a level middle section. This also impacts output interference. If an individual has to recall a six-item section first, that generates six times more chance of output interference in comparison to a four-item section.

Three types of recall probes were administered: the first segment probe, the second segment probe and the full list recall probe. The probe names are descriptive labels for the section of the presented list that the participants must focus on. The first and second segments

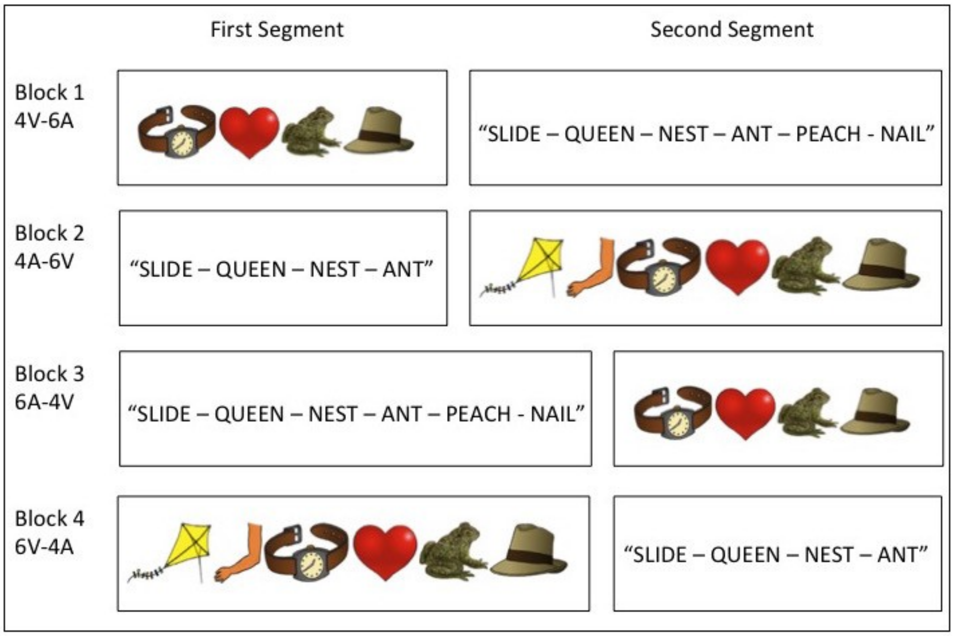

Figure 4.1: A schematic of the probed split span task.

will often map onto the concepts of SM and PM respectively, but the mapping is not exact, both because of issues over their quantification in children and choices over which items to recall from each segment. There were three possible recall questions: 1) What words can you remember? 2) What pictures can you remember? and 3) What can you remember? This corresponded to whether the segments were auditory or visual. Children were either asked for (1) then (2), or (2) then (1), or for (3). Thus, all items were solicited, but in different sequences. For probes that required specific items, participants were given 30s to accomplish this and then a further 30s to recall the non-probed items. When participants were given the probe to recall all items, they were given 30s to complete the recall phase. Within a block, each probe was allocated three trials.

4.3 Results

The experiment generated a rich, and potentially complicated set of data. To help present the results in a meaningful and informative way, the results section is divided into four areas.

First, free recall data was inspected to investigate serial position effects and to obtain PM/SM estimates. In the latter case, it was tested whether there was evidence that both adults and children showed modality effects, specifically elevated auditory recall in the recency section. The following sections investigated different elements of the split span task using serial position analysis. To fully understand adults' and children's performance, their overall recall performance under the full list probe was compared to their performance when given the first or second segment probe. The full list probe was an index of their natural recall strategy as they were not given any instruction as to which items to recall first. This will investigate the accessibility of primacy items as an indication of being able to retrieve target memory representations from SM. The visual and auditory recall of first and second segments were compared to examine whether the two different types of memory representations showed greater recall strength. In addition to this, in order to assess the robustness of the two different types of memory representations, the inverted modality effect was tested. This involved analysing participants recall when they had to recall the first segment of a list after being instructed to recall the second segment first. For completeness, all analyses have been included within this section. However, because not all is necessary to answer the key questions put forward in this experiment, to reduce distraction from the main analyses focus, some have been included as footnotes for the reader to access if they wish.

4.3.1 Serial position analyses of the free recall measures

Replicating the analytic approach adopted earlier (e.g. section 2.3.1), probability of first recall (PFR) and probability of recall (PR) were considered across the selected age range, investigating presentation modality and how that affects the serial position curves generated. The curves were further investigated using multiple pairwise comparisons with a Bonferroni correction to determine differences in the primacy and recency effects as a function of serial position.

Figure 4.2A and B illustrate the PFR curves broken down by serial position, age and presentation modality. Participants were most likely to initiate their recall with the last serial position (M = .347; SE = .019). In other words, final-item recall was the most popular starting point. The second most popular starting point was serial position one (M = .207; SE = .016), the first presented item. The next most popular starting point was the penultimate list item, position nine (M = .150; SE = .011). The PFR analysis involved a 2 (presentation modality: auditory vs. visual) x 10 (serial position: one to ten) x 4 (age: Year 1 vs. Year 3 vs. Year 5 vs. Adults) mixed factor ANOVA, which confirmed that PFR was not the same across serial positions, $F(9,1647) = 109.167$, $p = .001$, $\eta p^2 = .374$. However, the point at which participants began their recall did not differ as a function of presentation modality, $F(1,183)=.759$, $p = .385$, $\eta p^2 = .004$, or age, $F(3,183) = .437$, $p = .727$, $\eta p^2 = .007$.

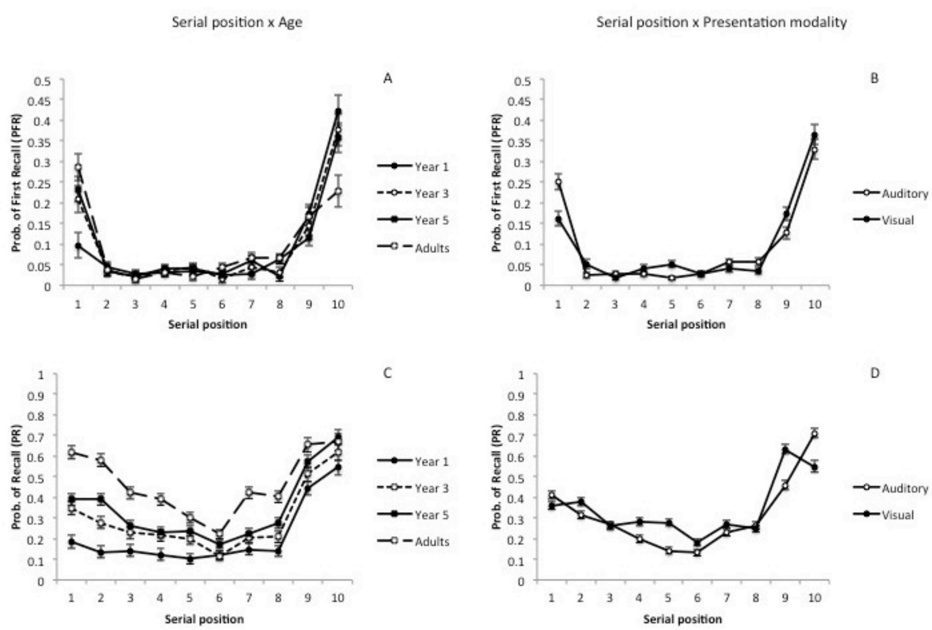

Figure 4.2: The probability of first recall (PFR) as a function of serial position and age (A) and serial position and presentation modality (B). The probability of recall (PR) as a function of serial position and age (C) and serial position and presentation modality (D). Error bars represent one standard error from the mean..

Despite no main effect of age, the four age groups differed in terms of preference for initiating recall with the first or last serial position, $F(27,1647) = 3.899$, $p = .001$, $\eta p^2 = .060$ (Figure 4.2A). Adults produced equivalent levels of PFR across the two serial positions, $F(1,42) = .982$, $p = .327$, $\eta p^2 = .023$, whilst all children groups showed a higher PFR for the final list item (Year 1: $F(1,42) = 44.617$, $p < .001$, $\eta p^2 = .487$ Year 3: $F(1,42) = 5.826$, $p = .020$, $\eta p^2 = .122$; Year 5: $F(1,52) = 4.133$, $p = .047$, $\eta p^2 = .074$).

Presentation modality influenced where participants' began their recall, $F(9,1647) = 5.156$, $p = .001$, $\eta p^2 = .027$ (Figure 4.2B). Recall of auditorily-presented items led to initiation of more first serial position reports, $t(186) = 4.299$, $p = .001$, whilst the visually presented items produced an inclination for participants' to begin their recall with the pre-recency positions two, $t(186) = 2.211$, $p = .028$ and five, $t(186) = 3.242$, $p = .001$.

The analysis of PR, illustrated in Figure 4.2C and D, further examined age-related and presented modality differences in the serial position curves generated. A 2 (presentation modality: auditory vs. visual) x 10 (serial position: one to ten) x 4 (age: Year 1 vs. Year 3 vs. Year 5 vs. Adults) mixed factor ANOVA showed the expected age-related increase in recall, $F(3,182) = 92.077$, $p = .001$, $\eta p^2 = .603$, and the significant effect of serial position, $F(9,1638) = 111.723$, $p = .001$, $\eta p^2 = .380$. A primacy effect was evident at positions one ($M = .386$; $SE = .016$) and two ($M = .347$; $SE = .015$) as they did not differ from each other ($p = .272$) but held significantly higher PR than positions three to eight (range: .156 - .263, all $ps = .001$). The recency effect was isolated to positions, nine ($M = .545$; $SE = .017$) and ten ($M = .630$; $SE = .019$), both of which differed from each other, and were significantly higher than the preceding positions (all $ps = .001$).

The serial position curves generated interacted with age, $F(27,1638) = 3.140$, $p = .001$, $\eta p^2 = .049$, attributed to the size of the primacy and recency effects (Figure 4.2C). Years 3, 5 and adults all demonstrated two-item primacy and recency effects whereby the first two serial positions did not differ from each other (p = 1.000), but were significantly higher than positions three to eight (all $ps < .05$). The recency effects were similar whereby positions nine and ten did not differ from each other, but were significantly higher than positions three to eight (all $ps < .05$). Year 1 only produced a two-item recency effect; the last two positions being significantly more accurate than all the remaining serial positions ($p < .001$).

It is noteworthy that recall of visual items exceeded that of auditory items, $F(1,182) = 15.957$, $p < .001$, $\eta p^2 = .081$, which did not differ as a function of age, $F(3,182) = .645$, $p = .687$, $\eta p^2 = .011$. However, the interaction between serial position and presentation modality, $F(9,1638) = 13.363$, $p = .001$, $\eta p^2 = .068$, highlighted the presentation modality impacted the first half of the presentation list (Figure 4.2D). Analysis of the first five serial positions revealed a higher PR for the visual condition compared to the auditory condition, $F(1,182) = .967$, $p = .001$, $\eta p^2 = .061$. The last five serial positions were also analysed to show both modalities generated equivalent levels of PR, $F(1,182) = .1.619$, $p = .205$, $\eta p^2 = .009$, which did not alter as a function of age, reflected in the non-significant interaction between the two factors, $F(3,182) = .834$, $p = .477$, $\eta p^2 = .014$.

4.3.2 PM and SM estimates

Consistent with section 2.3.6, PM and SM estimates were generated using Tulving and Colotla's (1970) method and the critical value seven. Table 4.1 reports the mean number of items recalled from each memory construct across the two modalities for each age group. A 2 (presentation modality: auditory vs. visual) x 2 (memory system: PM vs. SM) x 4 (age: Year 1 vs. Year 3 vs. Year 5 vs. Adults) mixed factor ANOVA with mean number of items recalled as the dependent variable was carried out. In line with previous analyses, an age-related increase in recall was evident, $F(3,182) = 100.935$, $p < .001$, $\eta p^2 = .625$, demonstrated by a Bonferroni posthoc test (all $ps < .001$). Participants' recall was predominantly based in PM than SM,

$F(1,182) = 104.866$, $p < .001$, $\eta p^2 = .364$. In addition, visual recall was greater than auditory recall, $F(1,182) = 28.162$, $p < .001$, $\eta p^2 = .134$.

Table 4.1: The mean number of items recalled as a function of modality, memory system and age. (one standard error from the mean).

	Year 1	Year 3	Year 5	Adults
Auditory				
PM	1.347 (.094)	1.736 (.099)	1.975 (.089)	2.403 (.099)
SM	.347 (.106)	.953 (.112)	1.277 (.101)	2.209 (.112)
Visual				
PM	1.757 (.100)	2.016 (.106)	2.258 (.099)	2.388 (.106)
SM	.583 (.127)	1.147 (.135)	1.371 (.121)	2.326 (.135)

The significant interaction between memory system and age, $F(3,182) = 8.331$, $p < .001$, $\eta p^2 = .121$, revealed that whilst adults showed no difference in their PM and SM recall, $F(1,42) = .642$, $p = .427$, $\eta p^2 = .015$, all three children groups from five- to ten-years showed higher recall from PM than SM (Year 1: $F(1,47) = 160.420$, $p = .001$, $\eta p^2 = .773$; Year 3: $F(1,42) = 31.520$, $p = .001$, $\eta p^2 = .429$; Year 5: $F(1,51) = 26.519$, $p = .001$, $\eta p^2 = .342$). All other interactions were non-significant (all *ps* > .05), indicating that visual recall produced the larger number of items recalled from both PM and SM, and this was consistent throughout all the age groups.

4.3.3 Developmental differences in the accessibility of primacy items

This section aimed to answer the question of whether adults and children could alter their natural recall performance to adhere to the probes given after the list presentation. Specifically, whether the first segment recall probe could elevate children's recall of the first segment of a list. This was achieved by comparing the first segment recall probe and the full list recall probes serial position curves, followed by the comparison of the second segment and full list recall probe performance. It was expected that the first segment recall probe would generate elevated recall in the first segment compared to the full list probe, whilst the second segment recall probe was expected to generate elevated recall in the second segment. This should be evident in significant interactions between recall probe and serial position. The adults' and children's performance were analysed separately in 2(probe: first segment vs. full list) x 10 (serial position: one to ten) x 3 (age: Year 1 vs. Year 3 vs. Year 5) mixed factor ANOVAs, carried out for each block (The adults analysis did not have age as an factor). The blocks were also analysed separately to determine whether the different sized first and second segments and their modality combination affected the accessibility of memory representations.

Figure 4.3 illustrates how children reacted to the different recall probes across the four different blocks of the split span task. The comparison of the full list and first segment recall probes showed children's full list strategy generated an overall higher level of recall than when they were instructed to recall the first segment items in blocks 1 - 3 (4V-6A: $F(1,140) = 89.273$, $p < .001$, $\eta p^2 = .389$; 4A-6V: $F(1,140) = 5.989$, $p = .016$, $\eta p^2 = .041$; 6V-4A: $F(1,140) = 142.926$, $p < .001$, $\eta p^2 = .505$). An exception was equivalent levels of recall regardless of the recall probe in block 4 (6A-4V), $F(1,140) = 1.868$, $p = .174$, $\eta p^2 = .013$. The expected age-related increases in recall was evident across all blocks [1] accompanied by substantial serial

[1]age effects: 4V-6A: $F(2,140) = 16.251$, $p < .001$, $\eta p^2 = .188$; 4A-6V: $F(2,140) = 28.013$, $p < .001$, $\eta p^2 = .287$; 6V-4A: $F(2,140) = 18.347$, $p < .001$, $\eta p^2 = .208$; 6A-4V: $F(2,140) = 16.429$, $p < .001$, $\eta p^2 = .190$

position effects. [2]

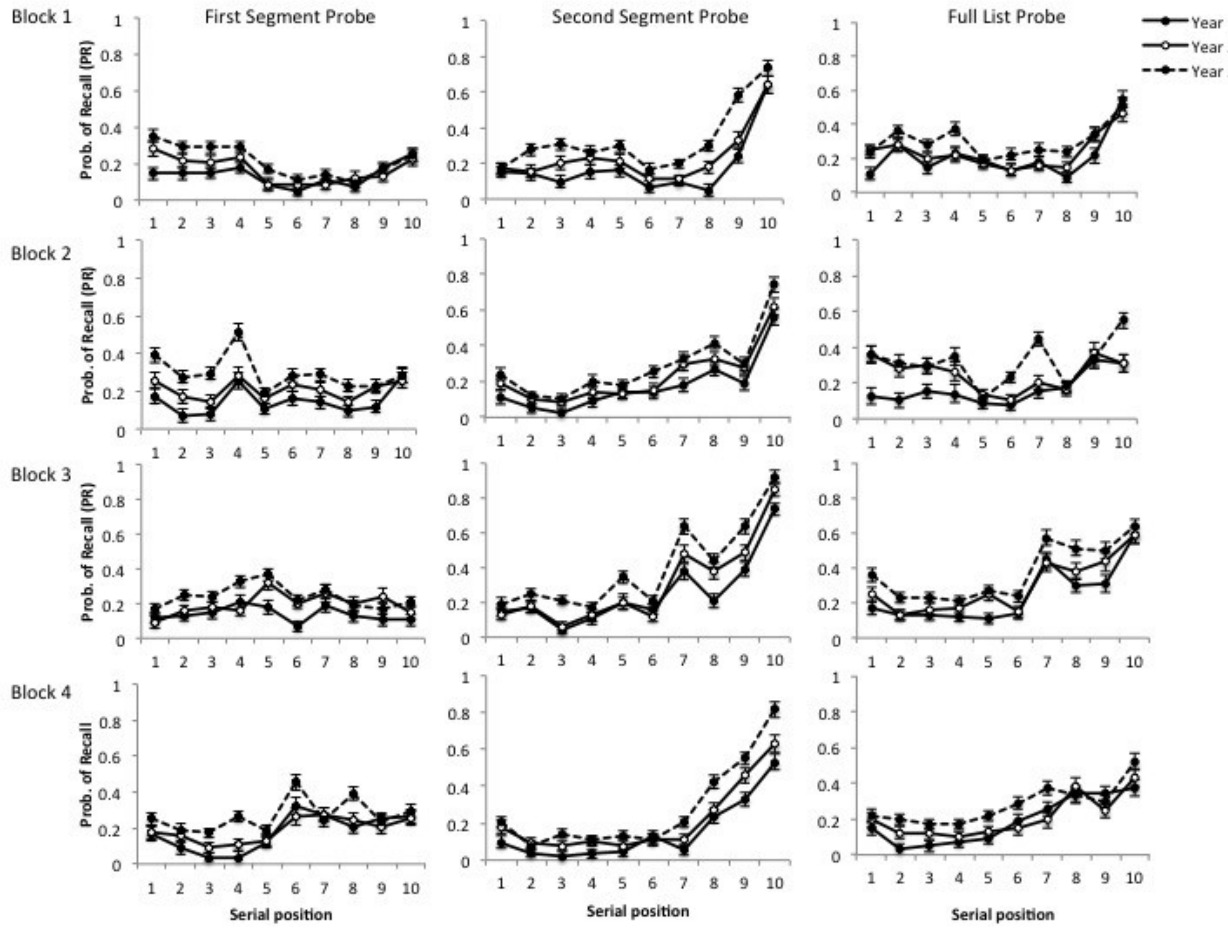

Figure 4.3: Children's probability of recall (PR) as a function of serial position, recall probe, block and age. Error bars represent one standard error from the mean.

The main effects were further qualified by all four types of list displaying a significant interaction between serial position and recall probe (4V-6A: $F(9,1260) = 10.607$, $p < .001$, $\eta p^2 = .070$; 4A-6V: $F(9,1260) = 8.799$, $p < .001$, $\eta p^2 = .060$; 6V-4A: $F(9,1260) = 40.268$, $p < .001$, $\eta p^2 = .223$; 6A-4V: $F(9,1260) = 8.552$, $p < .001$, $\eta p^2 = .058$). Despite children being instructed to recall the first segment, children's recall performance within that segment did

[2] serial position effects: 4V-6A: $F(9,1260) = 24.999$, $p < .001$, $\eta p^2 = .152$; 4A-6V: $F(9,1260) = 15.667$, $p < .001$, $\eta p^2 = .101$; 6V-4A: $F(9,1260) = 17.266$, $p < .001$, $\eta p^2 = .164$; 6A-4V: $F(9,1260) = 31.480$, $p < .001$, $\eta p^2 = .184$.

not differ from their full list recall strategy (4V-6A: $F(1,140) = .638$, $p = .426$, $\eta p^2 = .005$; 4A-6V: $F(1,140) = .271$, $p = .603$, $\eta p^2 = .002$; 6V-4A: $F(1,140) = .069$, $p = .793$, $\eta p^2 = .000$). Only block 4 (6A-4V) showed the expected finding; children generated a higher PR in the first segment when specifically instructed to recall items from that specific segment, $F(1,140) = 7.704$, $p = .006$, $\eta p^2 = .052$. To complete the interaction, children's full list recall performance generated a higher level of recall in the second segment in comparison to their recall of the same items under the first segment recall probe (4V-6A: $F(1,140) = 94.659$, $p < .001$, $\eta p^2 = .403$; 4A-6V: $F(1,140) = 9.805$, $p = .002$, $\eta p^2 = .066$; 6V-4A: $F(1,140) = 219.242$, $p < .001$, $\eta p^2 = .610$; 6A-4V: $F(1,140) = 22.655$, $p < .001$, $\eta p^2 = .139$).

The same type of analysis was carried out to determine how the second segment recall probe affected children's free recall performance, in comparison to their full list performance. This showed equivalent levels of recall regardless of recall probe. (4V-6A: $F(1,140) = .001$, $p = .979$, $\eta p^2 = .000$; 4A-6V: $F(1,140) = 1.091$, $p = .298$, $\eta p^2 = .008$; 6V-4A: $F(1,140) = 2.208$, $p = .140$, $\eta p^2 = .016$; 6A-4V: $F(1,140) = 2.244$, $p = .136$, $\eta p^2 = .016$). Block 1 (4V-6A) revealed a significant interaction between recall probe and age whereby all three age groups reacted differently to the recall probes. Year 1 recalled more items under the full list probe, $F(1,47) = 7.163$, $p = .010$, $\eta p^2 = .132$, Year 3 recalled an equivalent amount of items regardless of recall probe, $F(1,42) = .003$, $p = .954$, $\eta p^2 = .000$; whilst Year 5 recalled more items when instructed to recall items from the second segment, $F(1,51) = 4.918$, $p = .031$, $\eta p^2 = .088$. This was not evident in Blocks 2 - 4. [3]

The interactions between serial position and probe across all four blocks were also significant (4V-6A: $F(9,1260) = 8.094$, $p < .001$, $\eta p^2 = .055$; 4A-6V: $F(9,1260) = 24.908$, $p < .001$, $\eta p^2 = .152$; 6V-4A: $F(9,1260) = 12.402$, $p < .001$, $\eta p^2 = .081$; 6A-4V: $F(9,1260) =$

[3]Non-significant interaction between age and recall probe: 4A-6V: $F(2,140) = 1.406$, $p = .249$, $\eta p^2 = .020$; 6V-4A: $F(2,140) = .479$, $p = .620$, $\eta p^2 = .007$; 6A-4V: $F(2,140) = 2.493$, $p = .086$, $\eta p^2 = .034$.

18.528, p < .001, ηp^2 = .117). When recalling the first segment, the full list probe produced higher levels of recall than the second segment probe (4V-6A: $F(1,140) = 9.090$, $p = .003$, $\eta p^2 = .061$; 4A-6V: $F(1,140) = 47.420$, $p < .001$, $\eta p^2 = .254$; 6V-4A: $F(1,140) = 5.526$, $p = .020$, $\eta p^2 = .038$; 6A-4V: $F(1,140) = 24.130$, $p < .001$, $\eta p^2 = .147$). The second segment recall probe produced a higher PR than participants' full list recall performance when recalling items from the second segment (4V-6A: $F(1,140) = 8.711$, $p = .004$, $\eta p^2 = .059$; 4A-6V: $F(1,140) = 35.049$, $p < .001$, $\eta p^2 = .201$; 6V-4A: $F(1,140) = 12.655$, $p = .001$, $\eta p^2 = .147$; 6A-4V: $F(1,140) = 6.919$, $p = .009$, $\eta p^2 = .047$).

The same analysis was then carried out on the adults' data to determine whether they were able to change their recall strategy when instructed to (Figure 4.4). The significant effect of probe followed two patterns depending on the modality partition attributed to the blocks. In blocks 1 and 3 (visual-auditory format), the full list recall probe produced a higher level of PR than the first segment recall probe (4V-6A: $F(1,42) = 86.513$, $p < .001$, $\eta p^2 = .673$; 6V-4A: $F(1,42) = 61.442$, $p < .001$, $\eta p^2 = .600$). In contrast, blocks 2 and 4 (auditory-visual format), showed the first segment recall probe generated a higher level of PR than their full list recall (4A-6V: $F(1,42) = 14.902$, $p < .001$, $\eta p^2 = .262$; 6A-4V: $F(1,42) = 7.427$, $p < .001$, $\eta p^2 = .150$). As expected, serial position effects were evident across all four blocks. [4]

In addition, the four different types of list all showed a significant interaction between serial position and recall probe (4V-6A: $F(9,378) = 12.509$, $p < .001$, $\eta p^2 = .229$; 4A-6V: $F(9,378) = 3.772$, $p < .001$, $\eta p^2 = .082$; 6V-4A: $F(9,378) = 13.951$, $p < .001$, $\eta p^2 = .254$; 6A-4V: $F(9,378) = 9.436$, $p < .001$, $\eta p^2 = .183$). Blocks 1 and 3 (visual-auditory format) showed equivalent levels of recall within the first segment of the list regardless of the recall probe (4V-6A: $F(1,42) = 2.676$, $p = .109$, $\eta p^2 = .060$; 6V-4A: $F(1,42) = .926$, $p = .342$, ηp^2

[4] serial position effects: 4V-6A: $F(9,378) = 16.603$, $p<.001$, $\eta p^2 = .283$; 4A-6V: $F(9,378) = 28.640$, $p<.001$, $\eta p^2 = .405$; 6V-4A: $F(9,378) = 11.495$, $p<.001$, $\eta p^2 = .219$; 6A-4V: $F(9,378) = 8.017$, $p<.001$, $\eta p^2 = .160$.

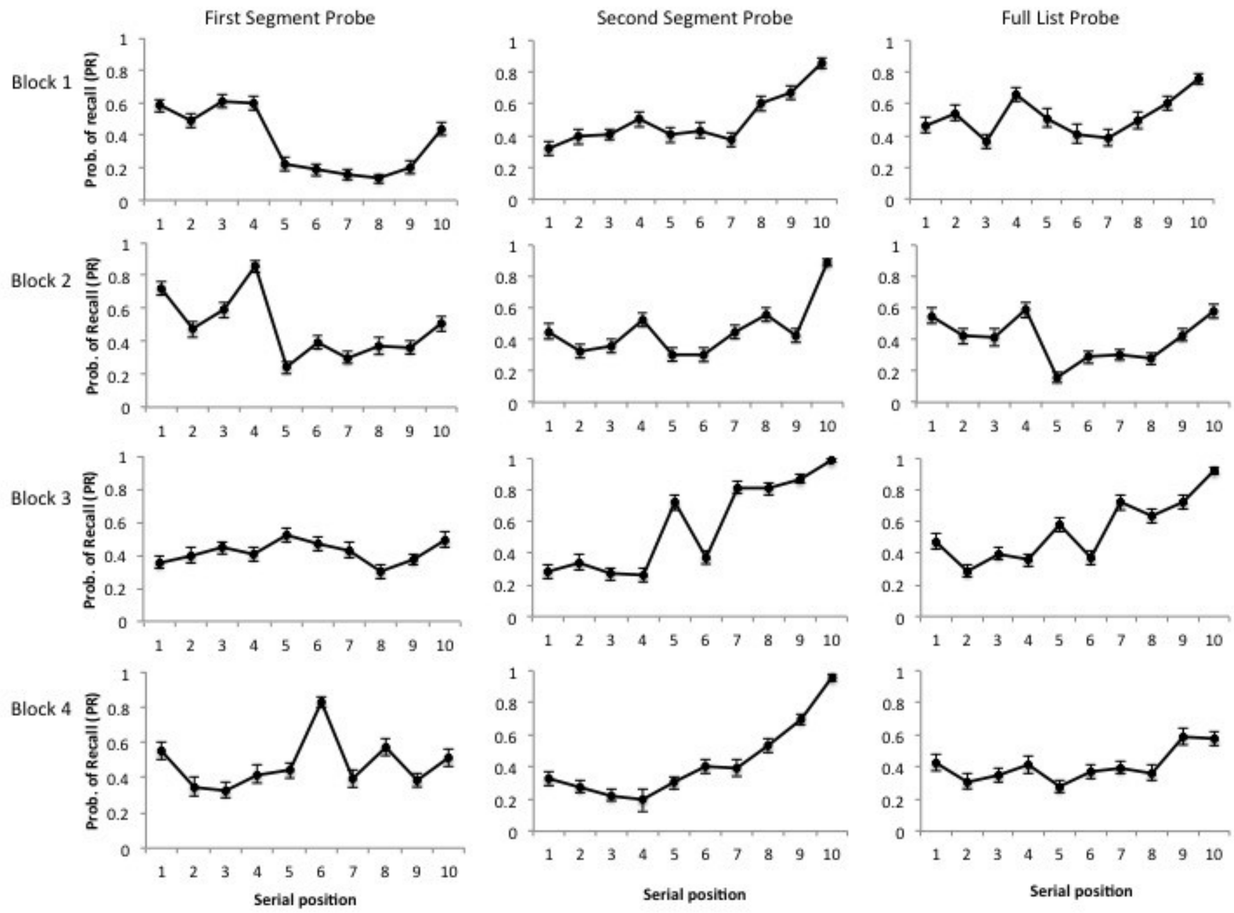

Figure 4.4: Adults' probability of recall (PR) as a function of serial position, recall probe, and block. Error bars represent one standard error from the mean.

= .022). Blocks 2 and 4 (auditory-visual format) showed that within the first segment, the corresponding probe generated a higher level of recall in comparison to the full list recall probe (4A-6V: $F(1,42) = 18.812$, $p < .001$, $\eta p^2 = .309$; 6A-4V: $F(1,42) = 19.105$, $p < .001$, $\eta p^2 = .313$). The recall of the second list segments was higher under the full list recall probed than the first segment probe across all four modality compositions (4V-6A: $F(1,142) = 96.656$, $p < .001$, $\eta p^2 = .405$; 4A-6V: $F(1,142) = 10.575$, $p = .001$, $\eta p^2 = .070$; 6V-4A: $F(1,142) = 220.409$, $p < .001$, $\eta p^2 = .608$; 6A-4V: $F(1,142) = 23.456$, $p < .001$, $\eta p^2 = .142$).

The second segment recall probes and the full list recall probes were also compared across the four blocks. Recall was equivalent across the two recall probes for all list types(4V-

6A: $F(1,142) = .008$, $p = .929$, $\eta p^2 = .000$; 4A-6V: $F(1,142) = 1.143$, $p = .287$, $\eta p^2 = .008$; 6V-4A: $F(1,142) = 2.430$, $p = .121$, $\eta p^2 = .017$; 6A-4V: $F(1,142) = 2.303$, $p = .131$, $\eta p^2 = .016$). However, the interaction between serial position and recall probe found for all list types illustrated that the second segment recall probe generated a higher PR of the corresponding list segment in comparison to the full list recall probe (4V-6A: $F(1,142) = 8.904$, $p = .003$, $\eta p^2 = .059$; 4A-6V: $F(1,142) = 34.551$, $p < .001$, $\eta p^2 = .197$; 6V-4A: $F(1,142) = 12.655$, $p = .001$, $\eta p^2 = .082$; 6A-4V: $F(1,142) = 6.834$, $p = .010$, $\eta p^2 = .046$). In contrast, the recall of the first segment demonstrated the opposite; the full list recall probe generated higher PRs than the second segment recall probe (4V-6A: $F(1,142) = 9.404$, $p = .003$, $\eta p^2 = .062$; 4A-6V: $F(1,142) = 45.696$, $p < .001$, $\eta p^2 = .245$; 6V-4A: $F(1,142) = 5.150$, $p = .025$, $\eta p^2 = .035$; 6A-4V: $F(1,142) = 25.205$, $p < .001$, $\eta p^2 = .151$).

4.3.4 The impact of presentation modality on the recall of primacy and recency items

Results showed that children's recall of the first segments were not elevated despite being instructed to recall those items first. Adults were able to do this, but only when the first segment was auditory. When it was visual, adults reverted to performing in the same manner as children. However, the question still remained whether any modality differences were evident within the first and second segments. Therefore, within the first segments, the question remains whether participants recall more visual items than auditory items, consistent with section 4.3.1? Further, is a modality effect evident within the second segments? To answer this, the auditory and visual recall of each section was compared.

The first segments of all four blocks were analysed. This included two separate mixed factor ANOVAs, one including the short first segments (blocks 1 [4V] and 2 [4A]) and the longer first segments (blocks 3 [6V] and 4 [6A]). Serial position performance as a function of recall probe is demonstrated in Figure 4.5. Analyses revealed that regardless of the number of items in the first segment, presentation modality did not affect children's level of recall (4V vs 4A: $F(1{,}139) = .354$, $p = .553$, $\eta p^2 = .003$; 6V vs 6A: $F(1{,}140) = 2.179$, $p = .142$, $\eta p^2 = .015$). Nonetheless, the expected age-related increase in the recall of the first segment was evident, (short first segment: $F(2{,}140) = 21.475$, $p < .001$, $\eta p^2 = .236$; long first segment: $F(2{,}140) = 20.829$, $p < .001$, $\eta p^2 = .229$), accompanied by significant serial position effects (short first segment: $F(3{,}417) = 15.234$, $p = .001$, $\eta p^2 = .099$; long first segment: $F(5{,}700) = 8.500$, $p = .001$, $\eta p^2 = .057$).

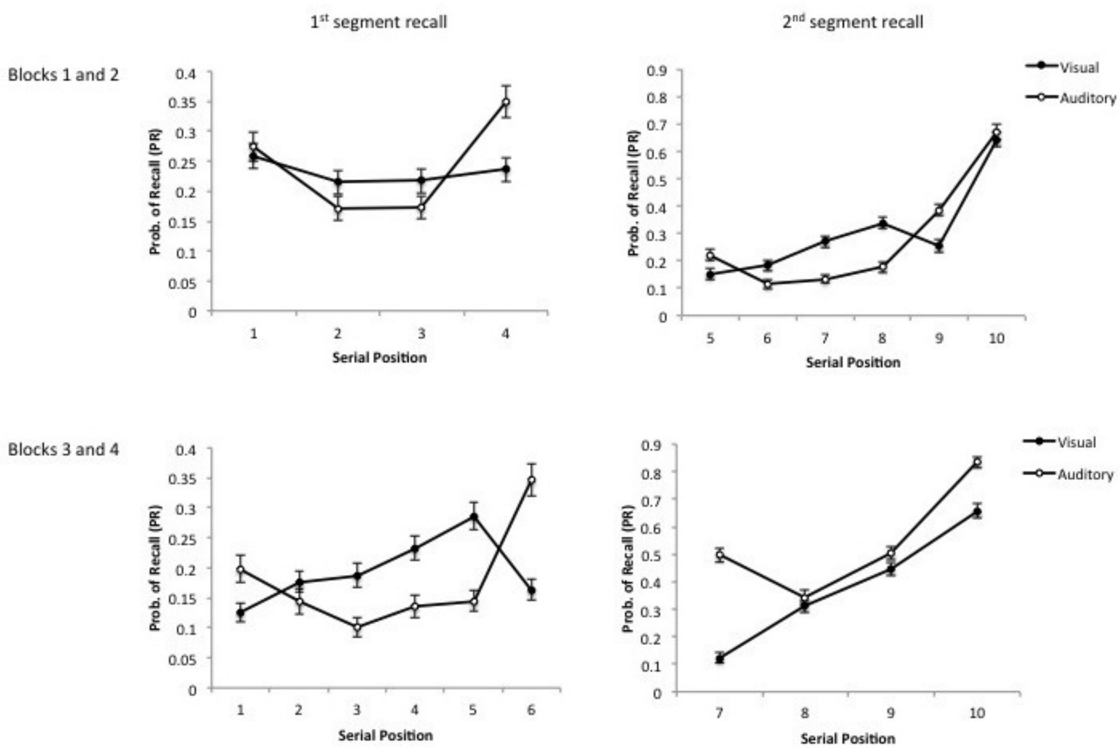

Figure 4.5: Children's probability of recall (PR) as a function of serial position and presentation modality. Error bars represent one standard error from the mean.

Both analyses produced significant interactions between serial position and presentation modality (4V vs 4A: $F(3{,}417) = 8.042$, $p = .001$, $\eta p^2 = .055$, 6V vs 6A: $F(5{,}700)$

= 22,527, p = .001, ηp^2 = .139). The only difference was higher auditory recall for the final, fourth serial position, $t(141)$ = 3.886, p = .001. The same interaction within the long first segments (6V vs. 6A) highlighted higher auditory accuracy for the first and last serial positions (position one: $t(142)$ = 3.025, p = .003; position six: $t(142)$ = 6.207, p = .001), reflecting a bowed serial position curve. In contrast, the visual condition showed a rising recency effect across the six positions with higher recall accuracy for the middle positions three to five (all $ts(142)$ = 3.557-4.836, all ps = .001). However, the three-way interaction between serial position, modality and age for the six-item first segment (6V vs. 6A), $F(10,700)$ = 2.148, p = .019, ηp^2 = .030, showed the three age groups reacted differently to the recall of the middle serial positions. [5]

Exploring the effect of presentation modality on the second segments involved the comparison of the long second segments in blocks 1 and 2 (6A vs. 6V) and the short segments in blocks 3 and 4 (4A vs. 4V, Figure 4.5). The recall of the long second segment showed no effect of modality, $F(1,140)$ = 2.732, p = .101, ηp^2 = .019. A significant interaction between serial position and modality, $F(5,695)$ = 16.428, p = .001, ηp^2 = .106, and a significant three-way interaction between serial position, modality and age, $F(10,695)$ = 1.957, p = .035, ηp^2 = .027 demonstrated all age groups showed the serial position and modality interaction, but at different points, Year 1: $F(5,235)$ = 6.145, p = .001, ηp^2 = .116; Year 3: $F(5,210)$ = 4.040, p = .002, ηp^2 = .088; Year 5: $F(5,250)$ = 10.375, p = .001, ηp^2 = .172. [6]

[5]Year 1 recalled more visual items at positions three, $t(47)$=3.665, p=.001 and four, $t(47)$=4.854, p<.001. Years 3 and 5 recalled more visual items at position five (Year 3: $t(47)$=3.551, p=.001; Year 5: $t(47)$=3.612, p=.001).

[6]Years 1 and 3 showed higher visual recall at positions seven (Year 1: $t(47)$=2.133, p=.038; Year 3: $t(42)$=3.884, p<.001) and eight (Year 1: $t(47)$=6.965, p<.001; Year 3: $t(42)$=2.235, p=.031). Year 5 extended this to positions five, $t(50)$=2.115, p=.039, seven $t(50)$=2.796, p=.007, and eight, $t(50)$=2.529, p=.015.

In contrast, recall of the short second segments in blocks 3 and 4 (4V vs. 4A) showed elevated auditory recall in comparison to visual recall, $F(1,140) = 87.554$, $p = .001$, $\eta p^2 = .385$. This was followed by a significant interaction between serial position and presentation modality. As a consequence of the auditory U-shaped curve, the first and last serial positions for the auditory modality were significantly higher than the visual modality (position one: $t(142) = 13.111$, $p = .001$, position four: $t(142) = 5.738$, $p = .001$).

Using similar analyses, the adults showed higher recall of the auditory short first segment (4A) compared to the corresponding visual short first segment (4V), in blocks 1 and 2, $F(1,42) = 17.053$, $p < .001$, $\eta p^2 = .173$. The significant effect of serial position, $F(3,126) = 4.864$, $p = .001$, $\eta p^2 =.225$, was followed by a significant interaction between the two factors, $F(3,126) = 7.099$, $p = .001$, $\eta p^2 = .145$. Whilst the auditory first segment generated a bowed serial position curve, with higher levels of recall for serial positions one and four (all $ts(42) < 3.131$, all $ps < .01$) the visual first segment generated a more even level of PR (Figure 4.6).

The long first segments in blocks 3 and 4 (6V vs. 6A) showed no effect of modality, $F(1,42) = 2.959$, $p = .093$, $\eta p^2 = .063$. Again the significant effect of serial position, $F(5,205) = 13.903$, $p = .001$, $\eta p^2 = .253$, was followed by a significant interaction between the two factors, $F(5,205) = 9.290$, $p = .001$, $\eta p^2 = .185$. Presentation modality facilitated different serial position curves. The first and last serial position generated higher PRs when the first segment was auditory in comparison to the steady recall of visual items (all $ts(42) < 2.957$, all $ps < .01$).

The second segments of the lists also demonstrated the modality effect (Figure 4.6); auditory second segments produced a higher level of recall than visual format regardless of the length of the segment (6A vs 6V: $F(1,42) = 8.477$, $p = .006$, $\eta p^2 = .168$; 4A vs 4V: $F(1,42) = 65.334$, $p = .001$, $\eta p^2 = .609$). The significant effect of serial position (6A vs 6V: $F(5,210) = 41.198$, $p = .001$, $\eta p^2 = .495$; 4A vs 4V: $F(3,126) = 47.946$, $p = .001$, $\eta p^2 = .533$)

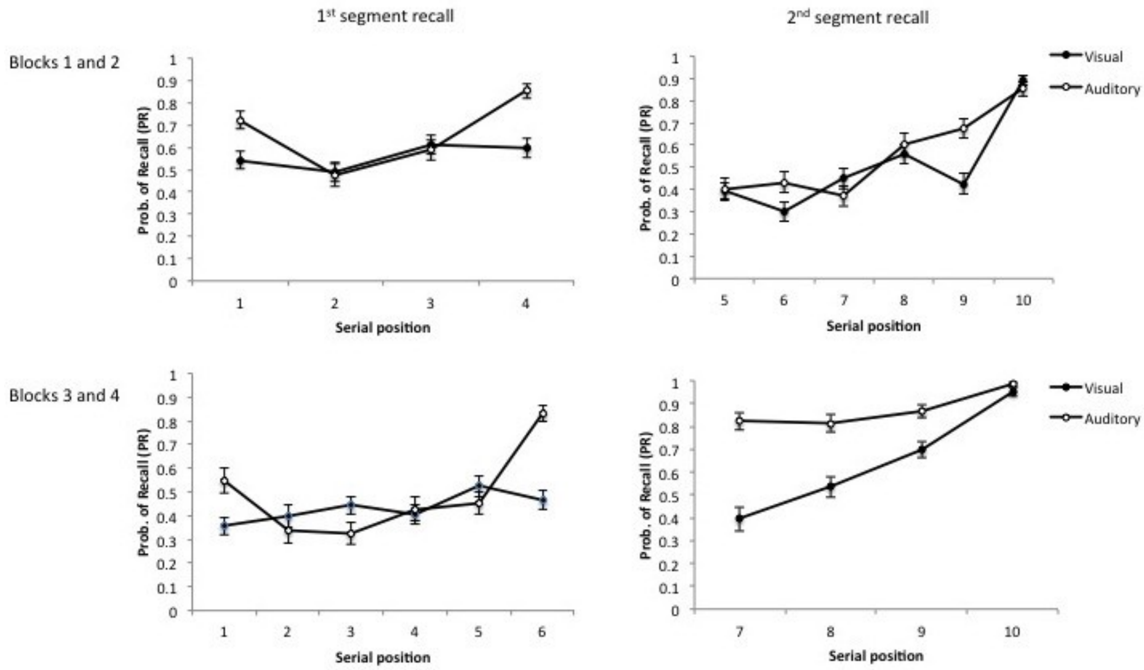

Figure 4.6: Adults' probability of recall (PR) as a function of serial position and presentation modality, broken down by SM recall and PM recall. Error bars represent one standard error from the mean.

was followed by a significant interaction between the two factors (6A vs 6V: $F(3,126) = 13.981$, $p = .001$, $\eta p^2 = .250$; 4A vs 4V: $F(5,210) = 4.399$, $p = .001$, $\eta p^2 = .095$). Within the long second segments, both modalities produced a rising recency effect. The recall of serial positions six, $t(42) = 2.525$, $p = .015$, and nine, $t(42) = 3.775$, $p < .001$, were higher in the auditory condition, but there was no difference between modalities in the recall of the final item, $t(42) = 1.094$, $p = .280$. The interaction surrounding the shorter second segment (4A vs. 4V) showed the auditory recall was higher than visual recall across all serial positions, except the last (all $ts(42) < 3.406$, all $ps < .001$).

4.3.5 The inverted modality effect in adults and children

The probed split span task enabled further investigation of whether the inverted modality effect is evident in adults and children. When participants were instructed to recall the second segment first, did they subsequently recall more visual or auditory items from the first segment? This involved the comparison of visual and auditory recall from the first segment in blocks 1 and 2 (4V vs. 4A) and blocks 3 and 4 (6V vs. 6A). Any diminished recall provides an indication of the fragility of memory representations as a function of presentation modality and output interference (Figure 4.7).

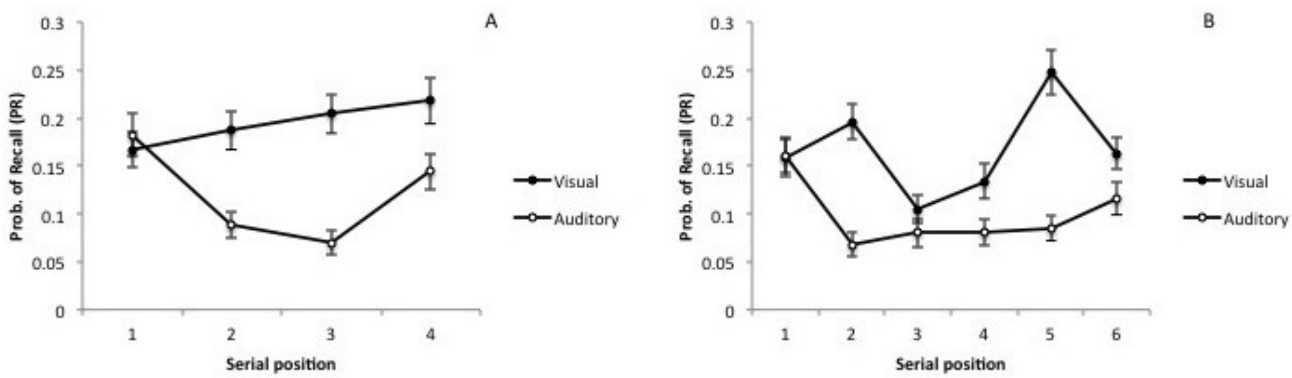

Figure 4.7: Children's inverted modality effect: Probability of recall (PR) as a function of serial position and presentation modality comparing the first segments in blocks 1 and 2 (A); blocks 3 and 4 (B). Error bars represent one standard error from the mean.

The four visual items in the first segment of block 1 (4V) demonstrated a recall advantage in comparison to the four auditory items (4A) from the corresponding segment in block 2, $F(1,139) = 30.035$, $p = .001$, $\eta p^2 = .178$. A significant effect of serial position, $F(3,417) = 3.163$, $p = .024$, $\eta p^2 = .022$, and age-related increases in recall were also evident, $F(2,139) = 12.143$, $p = .001$, $\eta p^2 = .149$. The only significant interaction was between serial position and modality, $F(3,417) = 6.781$, $p = .001$, $\eta p^2 = .047$, whereby visual recall was consistently more accurate between positions two to four (all $ts(142) = 2.749$-4.732, all $ps < .01$).

The comparison of blocks 3 and 4, which consisted of six visual (6V) or six auditory (6A) items in the first segment also showed a visual advantage, $F(1,140) = 44.412$, $p = .001$, $\eta p^2 = .241$, alongside a systematic increase in the recall of first segment items across the age range tested, $F(2,140) = 13.728$, $p = .001$, $\eta p^2 = .164$. A significant interaction between age and presentation modality, $F(2,140) = 3.946$, $p = .022$, $\eta p^2 = .053$, highlighted that only Year 1 and Year 5 showed this effect (Year 1: $F(1,47) = 33.519$, $p = .001$, $\eta p^2 = 416$; Year 5: $F(1,51) = 22.921$, $p = .001$, $\eta p^2 = .310$); whilst Year 3 produced equivalent recall regardless of modality, $F(1,42) = 2.828$, $p = .100$, $\eta p^2 = .063$.

The significant effect of serial position, $F(5,700) = 6.546$, $p = .001$, $\eta p^2 = .045$, was also followed by a significant interaction between serial position and presentation modality, $F(5,700) = 7.258$, $p = .001$, $\eta p^2 = .049$. Visual recall was higher for all serial positions (all *ps* $< .05$), with the exception of positions one, $t(142) = .000$, $p > .05$ and three, $t(142) = 1.313$, $p = .191$ (Figure 4.7). A significant interaction between serial position and age was also evident, $F(5,700) = 6.546$, $p = .001$, $\eta p^2 = .045$. [7]

In regards to the adults' performance, (Figure 4.8), the comparison of visual and auditory recall of the short first segments (4V vs. 4A) showed no effect of modality, $F(1,42) = .036$, $p = .851$, $\eta p^2 = .001$, but significant serial position effects, $F(3,126) = 6.957$, $p = .001$, $\eta p^2 = .142$. The interaction between the two factors approached significance, $F(3,126) = 2.539$, $p = .060$, $\eta p^2 = .057$. The comparison of the visual and auditory long first segments (6V vs. 6A) did produce a modality effect, $F(1,42) = 6.953$, $p = .012$, $\eta p^2 = .142$, with the visual condition producing a higher level of PR than the auditory condition. The significant serial position effect, $F(5,210) = 10.658$, $p = .001$, $\eta p^2 = .202$, was followed by a significant interaction between serial position and presentation modality, $F(5,210) = 8.632$, $p = .001$, $\eta p^2 = .170$. A single difference was evident at serial position five, $t(42) = 6.768$, $p = .001$.

[7] Serial positions one, two, five and six showed no differences across ages (all *ps* $> .05$). However the dipped recall of items three and four showed age-related increases in recalling the middle items (all *ps* $< .05$).

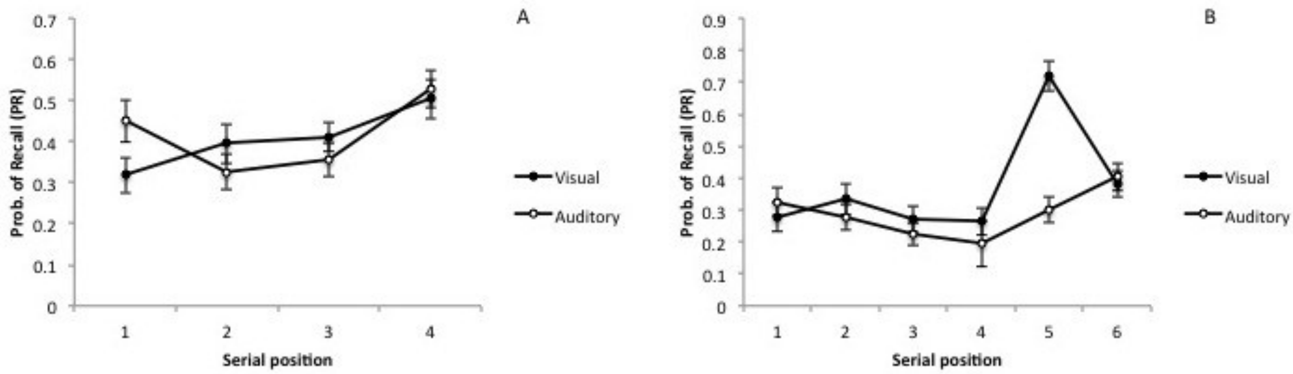

Figure 4.8: Adults' inverted modality effect: Probability of recall (PR) as a function of serial position and presentation modality comparing the first segments in blocks 1 and 2 (A); blocks 3 and 4 (B). Error bars represent one standard error from the mean.

4.4 Discussion

Experiment 3 aimed to investigate the accessibility and retrieval of memory representations from outside immediate focus, and how presentation modality and their representational codes affected this. An additional free recall paradigm manipulating presentation modality was administered to ascertain modality effects as an indication of differences in the active maintenance of auditory and visual information. To progress the findings and take it beyond the limitation of a traditional free recall task, the probed split span task was designed. The use of recall probes was designed to test the accessibility of memory representations that may not be recalled naturally. This would demonstrate a flexibility in adults' and children's recall strategy and specifically whether they were able to begin recall primacy items when instructed to do so. Presentation modality within the split span task was also used as a tool to examine the accessibility of different memory representations. This was assessed by comparing auditory and visual recall in the first and second segments of the lists, plus the inverted modality effect, indicating the extent to which auditory and visual memory representations are sustained and maintain their strength, ready for recall.

The introduction of modality-specific free recall trials shed light on modality differences cited in the literature, i.e. heightened recall for auditory recency items in comparison to visual recency items. The only modality difference evident was elevated recall of primacy visual items. Whilst the auditory serial position curve generated the progressive decline in the recall of beginning list items and a rising recency effect, converging with the typical U-shaped curve, the visual recall remained relatively stable throughout the pre-recency items. Overall, the visual modality produced a higher level of recall than the auditory format. Previous studies have demonstrated a visual advantage for serial positions in adults (Madigan, 1971; Metcalfe & Sharpe, 1985), which has now been extended to children aged five- to ten-years of age. This lends support for previous descriptions of pictures being better remembered than words by children (Bernbach, 1967; Cole et al., 1971; Siegel & Allik, 1973; Spitzer, 1976). Consistent with the explanation provided for the larger proportion of visual focal recall in the SIIT, the action of labelling an items acts as a form of bootstrapping, reinforcing the memory representation. This provided participants with the simultaneous, dual encoding of stimuli in an auditory and visual form, increasing it accessibility and probability of recall.

Estimations of PM and SM capacity increased between children age groups and again to the adult group. The interaction between memory system and age revealed that whilst adults showed no difference in the use of PM and SM, all three children groups produced larger PM estimates in comparison to their SM estimates. Of specific interest though was the fact that the interaction between memory system and presentation modality was non-significant, indicating presentation modality did not affect whether participants recalled more items from PM or SM. This also revealed no differences in the recall of auditory or visual items from PM.

It was surprising that a modality effect was absent in all groups. Inspection of Figure 4.2D does show rising recency with the auditory presentation, generating a higher PR for the last serial position (vs. the visual presentation). Theoretically though, it is consistent with the unitary, PM system described by the dual-store models (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965), in so far as the immediate memory system is invariant to the format of the input. This also applies to the dual-memory framework; individuals retain and manage auditory and visual items with the same regard, applying the domain-general allocation of attention to all memory representations actively maintained in PM.

The extension of the age range to five- to ten-years provided a wider observation of how children's performance changed across primary school. However, children's focus still remained on the final list items. Children were most likely to begin their recall with the final item and subsequently produced a more dominant recency effect in comparison to the primacy effect. The effect sizes surrounding each age group suggested that the probability of beginning recall with the final list item decreased with age, leading to adults' more balanced recall initiation of beginning recall with either the first or last list item. This re-ignites the notion that the description of participants beginning their recall with recency items followed by primacy items by the dual-store models is an over-simplification. There are individual differences in how participants' strategise their recall performance that must be incorporated into our understanding of the dual-mechanism account (Unsworth et al., 2011).

Following the finding of children's default recency strategy, one of the main objectives driving the use of the probed split span task was to ascertain the extent to which children were able to shift their recall focus from recency items to primacy items. Therefore, free recall lists were split into segments; the first segment reflected primacy sections of a list, and the second segment reflected recency sections. By instructing adults and children to begin their recall in the first segment of a list it should help facilitate the recall of the corresponding items. To start, it was evident that adults' and children's full list recall performance, an index of their natural recall strategy, did not differ in the level of PR when compared to their instructed second segment recall. This suggests that participants showed a greater tendency to follow a strategy that involved the recall of items from the end of the list, followed by the beginning items. As expected from the children's data, their natural recall strategy generated a higher level of recall in comparison to performance on the first segment recall probe, with exception to block 4 (6A-4V) that showed no effect of probe. Adults generated a slightly different pattern of performance. Blocks that followed an auditory-visual format (blocks 2 and 4) showed the first segment recall probe facilitated a higher level of recall than their natural recall strategy. For the visual-auditory format lists (blocks 1 and 3), adults showed the same pattern of performance as the children.

Participants' inability to access items within the first segments was further confirmed by the interactions between recall probe and serial position. Developmental differences in the recall of early presentation items was evident within children, reflected in the age-related increases in the recall of the first segments of lists. However, the comparison of children's recall from the full list probe and the first segment probe were equivalent, suggesting that children do not actually have easy access to retrieve items within the first segment, even when forced to do so. This was followed by the indication that regardless of whether memory items were auditory or visual, their recall of the first segments were equally low. This implies the type of memory representation did not affect children's ability to retrieve SM items when instructed to do so. All of children's memory representations were susceptible to displacement and being forgotten due to being managed in an immediate, active maintenance facility, which was not strong enough to resist distraction.

When adults were instructed to start recall in the first segment of the list, they were only able to show elevated recall when the list followed the auditory-visual format (blocks 1 and 3). This was lost when the stimuli were presented in a visual-auditory format (blocks 2 and 4). In addition, they showed an auditory advantage in the recall of the shorter first segments, but the effect did not extend to the longer first segments. This suggests that adults have an increased accessibility to auditory items in comparison to visual items when they are recalled first, but only for a small amount of items. This brings forward the argument that adults' recall of the first and second segments were characteristic of PM recall. As suggested by Jarrold et al. (2015), the recall of items from the beginning of a list does not definitely mean participants are retrieving those items from SM. Alternatively, they could be actively maintaining the first items presented to them and forgetting the rest of the list. Therefore, it is important to consider whether the recall of the first segments within the probed split span task is actually testing participants' ability to access items from a longer-term store or their ability to actively maintain sets of items for a duration of time to then be quickly unloaded at the point of recall.

The recall of the second segments highlighted that children did show an auditory advantage in the recall of the shorter segment, but was lost in the longer second segment. In comparison, adults maintained the auditory advantage for both types of second segments. The difference in recall between the auditory and visual items holds resonance with the modality effect and an auditory advantage when recalling recency items from PM (Conrad & Hull, 1968; Craik, 1969; Murdock & Walker, 1969). Therefore, despite it not being evident in the free recall trials, adults and children do show an immediate access to auditory information. This is in support of the consistent findings within the SIITs that children were able to hold more auditory items in working memory in comparison to visual items.

The partitioned nature of the split span task provided the chance to observe whether the sub-elements within list segments were retained within their own auditory or visual dual mechanisms. For this to be so, double primacy and recency effects within each segment need to be evident. The serial position curves found within each segment of a list were not dissimilar to the serial position curves of the modality-specific free recall trials (Figure 4.2D). It is possible therefore that the instruction to recall specific segments led participants to carry out their recall as would be expected in traditional longer free recall trials. However, careful observation of Figures 4.3 and 4.4 showed that participants did not show the same pattern of performance in both sections of the list i.e. a rising recency effect for visual items and a bowed serial position curve for auditory items. Therefore in the current situation, this task is being managed by one cognitive system incorporating both verbal and visual information.

The inverted modality effect (Beaman, 2002; Beaman & Morton, 2000), was obtained in five- to ten-year olds. Regardless of differences in the number of items in each of the first and second segments, the visual stimuli were more robust, generating a higher level of PR once participants recalled the second segment items first. This effect was interpreted as a reflection of how different kinds of memory representations are managed and their susceptibility to output interference. This type of interference occurs when the initial act of recall interferes with the retrieval of subsequent information. The recall of memory items probed from the end of a list results in output interference for the rest of those items actively maintained. Therefore, all subsequently recalled items are argued to be retrieved from SM (Raymond, 1969). The children's data suggests that whilst auditory information may be highly accessible, it is also vulnerable to interference, and thus not stored in SM. Further, it is also at a disadvantage as children are not equipped with the rehearsal and maintenance strategies necessary to stop interference and displace them into a longer-term store. Visual information does receive additional processing as participants have to translate the visual picture into a phonological code. Therefore, the management of the two representational codes preserves the memory representation in SM, generating its strength in the face of interference.

Adults only showed evidence of an inverted modality effect in the longer, six-item SM section, suggesting that the number of items presented for recall affected whether the visual advantage was evident or not. However, this needs to be treated with caution. The significant effect seems to be attributed to a single serial position that shows significantly elevated visual recall in comparison to auditory recall of this position. The remaining five positions are all recalled at equivalent levels across the two modalities. Thus, it is still possible that the auditory and visual memory representations were equally durable in the face of interference, which needs to be further investigated.

Overall, this experiment has shown that within a free recall paradigm the output strategy that participants are comfortable with is crucial to the recall process. In this case, children still showed their default recency output strategy to produce their highest level of recall. It was not possible to force them to produce an enhanced primacy effect even when instructed to do so. This suggests that children aged five- to ten-years old are not able to access items presented earlier in a list, even when they know that they may need to recall such items. Some of the problems in using free recall to derive PM and SM scores have been identified and discussed in previous chapters. Particularly relevant is that they are not independent of each other within a free recall paradigm. The probed split span task offers converging evidence for particular memory processes but is does not solve these interpretive problems. In the next chapter, empirical work specifically addresses the characterisation of SM, further qualifying age-related and individual differences in the ability to carry out contextual, cue-dependent search processes and the cognitive underpinnings that children need to develop.

Chapter 5

The role of cues and contextual support in the characterisation of SM

5.1 Experiment 4: Introduction

Children are heavily reliant on the active maintenance and recall of items from PM. The free recall data collected and discussed in Chapters 2 and 3, the serial position curves generated plus methods to extract PM and SM (Tulving & Colotla, 1970) emphasised that the majority of recall from children is based on the output of immediate information. This was still the case when children were instructed to recall primacy items in Experiment 3, believed to be retrieved from SM. Adults on the other hand were able to juggle the recall of immediate information but also information that is retrieved from a longer-term store. One possible explanation for the differences between adults' and children's performance is that the developmental trajectory of SM emerges much later in childhood. Alternatively, free recall tasks may not be sensitive enough to tap into children's use of SM. This chapter aims to address these questions, tracking developmental differences in the ability to search and retrieve information, but also correlational analyses linking whether these specific process are linked to participants' WMC.

Based on the dual-memory framework (Unsworth & Engle, 2007b), not all information can be actively maintained, and therefore cue-dependent search and retrieval processes are required to retrieve task-relevant information from SM. This specific construct is reliant on cue-dependent search processes to retrieve memory items that are no longer in PM, or the focus of attention, and therefore displaced in SM. To demonstrate why the use of SM might be more difficult for individuals than PM, the accessibility of memory items from the two different systems needs to be compared. Target memory items that are actively maintained in PM are in a highly accessible state, and the attentional demands of retrieval should be relatively small (Cowan, 1999). In contrast, target memory items stored in SM are in a less accessible state, requiring attention-demanding retrieval processes (Kane & Engle, 2000). All of this is under the direct control of the individual (Shiffrin, 1970; Shiffrin & Atkinson, 1969; Unsworth & Engle, 2007b).

Research that has investigated retrieval processes within SM has predominantly used free recall paradigms. Unsworth and colleagues assessed individual differences in the use of SM (Unsworth, 2009; Unsworth et al., 2011; Unsworth & Engle, 2006a, 2007b), to show low-WMC adults recalled fewer SM items than high-WMC individuals (e.g Unsworth & Engle, 2007b; Unsworth, 2009). Researchers have also applied the use of SM as a potential explanation for low WMC in atypical populations. Adolescents diagnosed with ADHD are found to have a SM deficiency compared to those without ADHD, whilst PM remains intact (Gibson et al., 2010). The children literature discussed in Chapter 2, showed a linear increase in SM use with increasing age (Cole et al., 1971; De Alwis et al., 2009; Thurm & Glanzer, 1971), which was supported by the findings of the current thesis.

One has to consider whether free recall is an appropriate task to examine the development of SM in children. The ability to retrieve target items is an attentionally demanding process. The individual has to generate their own internal cues (which is attention demanding in the first place) for memory representations that have been shown at a relatively quick rate. This makes it hard for them to use maintenance strategies such as rehearsal or elaborative encoding (Healey & Miyake, 2009). This is even trickier for children of whom rehearsal processes do not emerge until seven- to eight-years of age (Flavell et al., 1966; Gathercole et al., 1994). Therefore those items that are displaced into SM and not forgotten are even less accessible, due to weaker memory representations.

In order to investigate how SM develops, away from the difficulties of a free recall task, and the SIIT, two tasks were designed that solely measured this specific construct: the cued listening span task and the delayed cued recall task. The tasks were developed with the objective of both showing increased SM use as a function of age, and providing a more sensitive investigation, tapping into the cognitive mechanisms that underlie the specific cognitive construct. This is opposed to just simply providing an estimate of use, based on the free recall data. The cued listening span task focused on providing indications of the use of cues to de-limit the search set and access target information, whilst the delayed cued recall task investigated the retrieval process itself.

As part of the design of the tasks, it was important to create a situation in which children could not rely on PM to complete the task. Unsworth and Engle (2008) claimed as part of SM retrieval, it requires the ability to retrieve items from outside the focus of attention. As previously addressed in Chapters 2 and 3, the focus of attention (Cowan, 2001) is conceptually similar to PM and it has been highlighted in previous chapters that children predominantly base their recall in PM and not SM. By removing this opportunity, they are not influenced by their default strategy, thus forcing them to try and use SM in order to be successful at the task. In turn this should provide a more reliable index of the age at which children are systematically able to access and retrieve memory representations from SM and its contribution to WMC.

One of the challenges children face is the generation of effective internal cues, which is a demand on attentional resources (Craik et al., 1996). Both of the tasks in Experiment 4 used external cues. Craik et al. (1996) investigated the attentional costs of encoding and retrieval in a dual-task paradigm using free recall, cued recall and recognition tasks. The results indicated that concurrent recall in the free recall task was affected the most by secondary task performance, followed by the cued recall and finally the recognition task. This led Guez and Naveh-Benjamin (2006) to suggest that internal cue generation is one of the most attention demanding aspects of retrieval. These findings applied to the current research suggests that testing children on free recall paradigms was the hardest situation for them. In order for them to have been successful they would have had to use search and retrieval process for a lot of items, which may have over exceeded their SM capacity. Therefore, by providing external support, in the form of external cues, it allows individuals to combine external and internally generated contextual information to focus the search on items stored in SM (Unsworth, 2009). This enables the cued recall searches to be more focused than free recall searches, which children seem to struggle with. If too many irrelevant items are included in the search set, the probability of selecting the correct representation will be very small. However, the use of an external cue will cause the search to be heavily dependent on the association between the cue and response and the ability to retrieve the target response from the cue. Thus, developmental differences in performance could be explained as a deficiency in the ability to focus the search and retrieval processes necessary to recall target memory items.

The first task presented here is called the cued listening span task. In order to be successful at complex span tasks individuals have to successfully retrieve items under conditions of interference (Unsworth & Engle, 2006a). Under the dual-memory framework complex span tasks are believed to be a predominantly SM based task. The first storage item is actively maintained in PM, until the point of processing. Due to individual's attention being allocated to completing the processing element of the task, the storage items are displaced into SM. This implies that the age-related increases in WMC are reflective of increased use of SM. This was the basis of the cued listening span task. By combining the use of external cues, the task assesses the accessibility of memory items believed to be forgotten. If participants are able to recall cued items, limitations in childrens use of SM is not a storage issue within the memory construct, it is the ability to use appropriate cues to de-limit the search, followed by the ability to retrieve target memory representations.

To explore the nature of contextual cue-dependent retrieval, two types of contextual cues were used: a sentence- and word-cue. By using this type of cue it delves into the continuum of cues used in the SM search process (Glenberg et al., 1980). The question is whether the more specific word cue will focus the search process to a greater extent than the contextually based sentence cue, and whether this is consistent across the entire age range. The use of sentence cues holds theoretical similarities with the notions of the recall reconstruction hypothesis (Cowan et al., 2003; Towse et al., 2008b, 2010), showing how contextual information enhances recall performance. In complex span tasks, individuals draw on the memory of a sentence using thematic and semantic contexts to access the target items. For example, when completing a listening span task, sentential information can facilitate the recall of target items. Therefore, participants encode more than just the target memory words, they can use information from linguistic processes to support access to the relevant information (Cowan et al., 2003; Towse et al., 2008b, 2010). A converging interpretation of reading span tasks by Osaka et al. (2002) demonstrated that the semantic processing of the sentence plays an important role in the recall of storage items. When a sentence is used as the processing element of a complex span task, participants have to encode the meanings of words from the sentence and decide which words are core and need to be integrated into the sentence. At recall, an active search then takes place, labelled as a “mental focus”, which facilitates the retrieval of storage information. Integral words from the sentence that hold associations with the storage items make the mental focus easier to carry out and recall performance is enhanced.

The argument that contextual information is important in the reactivation or reconstruction of memory representations is associated with the notion of a cooperative relationship between the processing and storage elements of the complex span task (Towse et al., 2010). From this perspective, the sentence cue should be a greater aid in reactivating the memory representation. In contrast though, some may consider the complex span task to just be a dual task and there is an independence between the processing and storage. In this situation, one may expect the word cue with its specific association to the storage item to be the most effective. The sentence cue will be less effective as participants will not have encoded the thematic information from the sentence. One final alternative also needs to be considered that children do not use SM, and therefore cueing will not improve their memory performance.

The second task, called the delayed cued recall task was based on work by Miyake and Friedman (2004). Their investigation examined why reading span tasks are better predictors of cognitive abilities than simple span measures. Miyake and Friedman (2004) used a variety of tasks that tap into the different component skills argued to be involved in complex span tasks (word span, word knowledge, sentence verification times, proactive interference). They found the only task to eliminate the correlation between reading span tasks and cognitive abilities was the delayed cued retrieval task. The authors concluded that attention-mediated abilities are required to use retrieval cues to reactivate/reconstruct target memory items from long-term memory. The notion of reconstruction as part of this task holds ties with the recall reconstruction hypothesis (Cowan et al., 2003; Towse et al., 2008b).

As an investigation into SM, key to this task was the word “delayed”. Items actively maintained in PM are affected by distractor activity (Glanzer & Cunitz, 1966; Postman &

Phillips, 1965). By implementing a distraction element to the task, attention is allocated elsewhere and those items held in PM are either forgotten or displaced into SM. This posits the risk that the items presented prior to the distractor activity will be forgotten, especially in the youngest five- to six-year olds who have not yet established the use of maintenance strategies. Nonetheless, the adoption of this task for the current investigation aims to provide age-related increases in accuracy but age-related decreases in response time (RT) as an index of efficiency in the use of retrieval processes from SM across children aged five- to ten-years. Two versions of the delayed cued recall task were implemented: an adult version that used the same stimuli as Miyake and Friedman's delayed cued retrieval task and a child version with age-appropriate stimuli. Whilst adults took part in both versions of the task, children only needed to complete the children's task.

Overall, data was collected on children aged five- to ten-years old and adults, to ascertain developmental differences in contextual cue-dependent search processes and retrieval in tasks where active maintenance of information is not possible. The experiment followed three main aims. Firstly, the cued listening span task will show how different types of contextual information facilitate recall from SM. It will determine whether adults and children find the thematic, sentence cue a better recall aid than the specific word cue. This in turn will provide insight into the types of contextual information children need to use as part of retrieving information from a long-term store. Secondly, the delayed cued recall task was designed to specifically focus on the developing efficiency of retrieval mechanisms required to contribute to WMC. The two tasks will hopefully provide insight into the developmental trajectory of SM providing information as to why children show very low SM use in free recall settings. Finally, bringing all measures together, the correlational data between the two SM task and WMC will be examined to determine whether controlled search and retrieval processes are a contributor to WMC.

5.2 Methods

5.2.1 Participants

Parental consent was gained for 145 children in Year 1 (five- to six-year olds, N = 48, M = 6:0 years, range: 5:05 6:07 years, 27 females); Year 3 (seven- to eight-year olds, N = 43, M = 7:11 years, range: 7:02 8:06 years, 21 females) and Year 5 (nine- to ten-year olds, N = 52, M = 10:00 years, range: 9:02 - 10:07 years, 34 female). Two sets of adults were used in this experiment. Those participants who took part in the split span task, also carried out the cued listening span task (N = 62; M = 19.10 years, range: 18.02 - 29.05 years, 35 female). A further 33 adult participants were recruited from Lancaster University (M = 19.08 years, range: 18:08 - 23:11 years, 21 female), all of whom gave full consent to undertake the study.

5.2.2 Materials

A corpus of 139 words were selected, 88 for the cued listening span task and 51 for the delayed cued recall task. The chosen words were placed into semantic categories for the delayed cued recall task based on the work of Overschelde et al. (2004). Stimuli for each semantic category were selected through the collection of pilot data. Using 20 target categories, adults were asked to write down the first three nouns within that category that came to mind. Items recalled 50% or more were excluded as potential stimuli (Appendix II). For example, within the semantic category fruit, the nouns apple, banana were excluded from stimuli selection due to being recalled 85% and 55% of the time respectively. Based on the pilot data findings, 15 semantic categories were selected that were appropriate for the youngest age range of five- to six-years (Morrison et al., 1997). This was to reduce the chances of the delayed cued recall task being confounded by word associations (Appendix III). By removing the common associations, participants would be more likely to have to retrieve the target memory representation from

SM. An additional adult version of the delayed cued recall task was generated. Thus 51 additional words were also selected, taken from Overschelde et al. (2004), replicating Miyake and Friedman's version of the task. The stimuli for this task were recorded in a female voice.

Within the cued listening span task, the cues necessary for the sentence cue condition were taken from the sentences used within the complex span task. Cues for the word-cue condition were selected from Edinburgh Associative Thesaurus. Cues were chosen on the basis that they were related to the target word, but not related to the cue chosen in the sentence cue condition for the same target word (Appendix IV). The sentences for this task were also recorded in a female voice.

5.2.3 Design and Procedure

All tasks for this experiment were run on PsychoPy software (Pierce, 2007, 2009). Overall this experiment followed a mixed factors design. All participants took part in the delayed cued recall task and a baseline measure of WMC was recorded. Adults actually took part in two versions of the delayed cued recall task: the child version generated by the experimenter and the adult version used by Miyake and Friedman (2004). Participants were split into the different cue groups for the cued listening span task.

5.2.4 Cued listening span

The span task was a sentence completion task based on the work by Towse et al. (1998b), previously used in Chapter 3 (section 3.2.5). List lengths varied between two and five items, presented incrementally, including three trials per list length. This was consistent with the list lengths used in Experiments 1 - 3. A schematic presentation of the task is presented in Figure 5.1. All participants began the task whereby participants have to complete two sentences and store the two words. Following this conventional procedure for testing span, cues were used to help aid the recall of the target items that were not reported prior to this point. Once participants had completed their recall they were given cues to help recall items that they had not been able to previously. Participants were allocated to one of three conditions: no cue, sentence-cue or word-cue. For example, the sentence "I waved goodbye with my ?" Participants were expected to recall "hand". If this was not possible and they were in the sentence cue condition they would be given the word "wave", taken from the sentence. If they were in the word-cue condition, they would be given the word "gloves". If participants were allocated to the no-cue condition they carried out the task as a conventional listening span task.

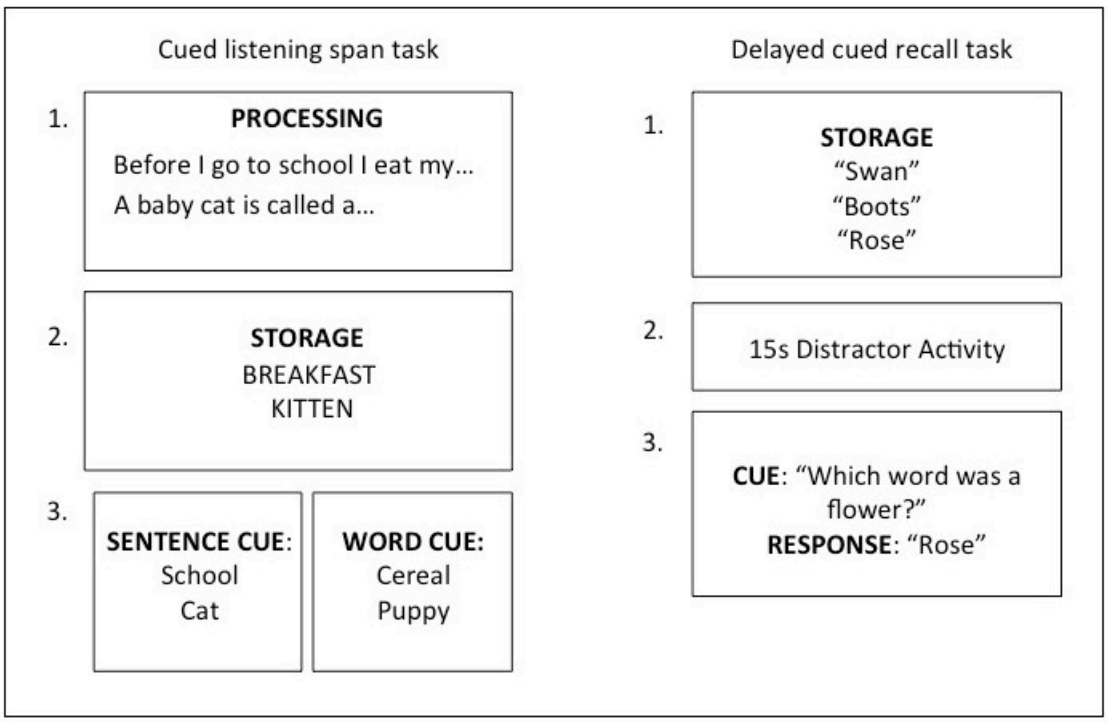

Figure 5.1: A schematic demonstration of the cued listening span task and delayed cued recall task.

5.2.5 Delayed cued recall task

For this task participants were required to listen to three unrelated, concrete nouns. All were presented at a rate of one word per second, with a 250ms interstimulus interval between each stimuli (see Figure 5.2.5). Following, a 15s distractor activity, participants were asked which word was from a specific semantic category. A total of 15 trials were included in this task, manipulating the serial position of the target recall item. Therefore, there were five trials for each serial position. Two measures were recorded: correct response for each serial position plus the time taken to respond (RT).

In regards to the distractor activity, adults had to count back in threes from a random three-digit number that appeared on the screen, whilst children had to count the hidden pictures in a visual scene. Both distractor activities lasted 15s, a modification from the original task by Miyake and Friedman (2004). To make the task more appropriate for children, it was decided that a counting task would provide enough distraction to displace memory items from PM, without overloading their processing and storage capacities.

5.3 Results

5.3.1 Cued Listening Span Task

Following a between-subjects design, participants were placed into one of three conditions: no cue, sentence-sue or word-cue condition (Table 5.1).

Table 5.1: A breakdown of participants for the cued listening span task

Year group	No cue	Sentence cue	Word cue
Year 1	16	16	16
Year 3	15	14	14
Year 5	18	18	16
Adults	21	20	21

Firstly, participants' baseline working memory performance was analysed to determine whether there were any differences between the cued conditions (Figure 5.2A). A 3 (condition: no cue vs. sentence cue vs. word cue) x 4 (age: Year 1 vs. Year 3 vs. Year 5 vs. Adults) ANOVA using the proportion of correct recall as the dependent variable revealed the expected age-related increase in complex span recall, $F(3,187) = 211.118$, $p = .001$, $\eta p^2 = .783$, using a Bonferroni posthoc test (all $ps < .001$). A significant condition-related effect, $F(2,187) = 27.593$, $p = .001$, $\eta p^2 = .239$ was also explained through posthoc analysis. The no cue condition produced significantly lower recall than both cued conditions (both $ps < .001$), whilst the cued conditions did not differ from each other ($p = 1.000$). However, this effect was only evident in Year 5 and adults (Year 5: $F(2,51) = 25.888$, $p = .001$, $\eta p^2 = .514$; Adults: $F(2,44) = 34.721$, $p = .001$, $\eta p^2 = .623$). Years 1 and 3 produced equivalent baseline performances across conditions (Year 1: $F(2,47) = .062$, $p = .940$, $\eta p^2 = .003$; Year 3: $F(2,42) = 2.187$, $p = .126$, $\eta p^2 = .099$).

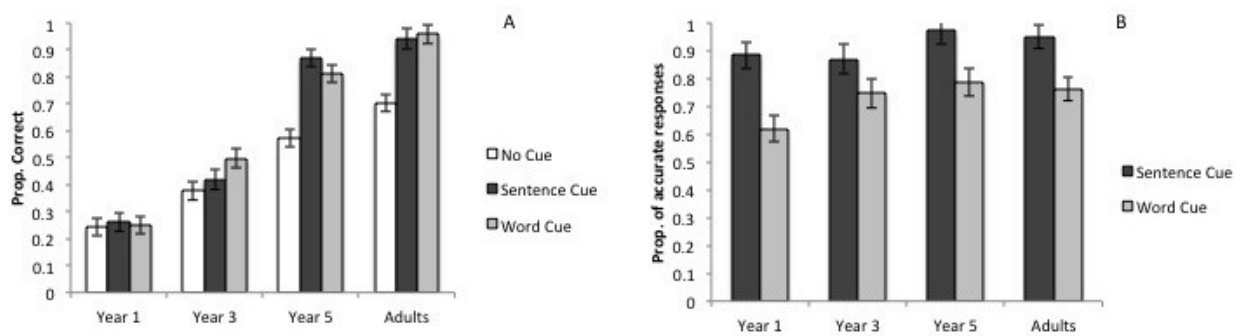

Figure 5.2: The proportion of baseline recall at the listening span task(A); the proportion of correct recall after cue administration, as a function of age and cue conditions (B). Error bars represent one standard error from the mean.

In order to determine the effectiveness of the two different types of cues the proportion of correct recall was calculated from the total number of cues administered (Figure 5.2B). This provided an index of the accessibility of memory items as a function of cue type.

The analysis revealed a significant effect of cue condition, $F(1,126) = 30.950$, $p = .001$, $\eta p^2 = .206$, whereby the sentence cue condition produced a higher total proportion of correct recall after cue administration ($M = .920$; $SE = .024$) in comparison to the word cue condition ($M = .730$; $SE = .024$). An age-related increase in the effectiveness of cues in triggering the recall of target memory items was evident, $F(3,126) = 2.789$, $p = .044$, $\eta p^2 = .066$. A posthoc test using a Bonferroni correction demonstrated Year 1 were least successful at using the cues in comparison to Year 5 ($p = .040$); there were no differences across the remaining age groups (all $p > .05$). Yet, the interaction between two factors was non-significant, $F(3,126) = .681$, $p = .565$, $\eta p^2 = .017$, thus indicating all age groups reacted in the same manner to the two different cues.

5.3.2 Delayed Cued Recall Task

This analysis assessed adults' and children's ability to recall target items after a distractor activity. This involved using the proportion of correct recall and RT as an index of developmental differences in retrieval ability. Firstly, adults' performance on the two different versions of the task was compared to determine whether there were any differences in their performance as a consequence of the different adult and children stimuli. Two 3 (serial position: position one vs. position two vs. position three) x 2 (experiment version: children vs. adults) mixed factor ANOVAs were carried out on the two dependent variables, proportion of correct recall and RT. In terms of accuracy, the proportion of correct recall did not differ across experiment versions, $F(1,29) = 3.551$, $p = .070$, $\eta p^2 = .109$. A significant effect of serial position was evident, $F(2,316) = 33.387$, $p = .001$, $\eta p^2 = .174$. Multiple pairwise comparisons using a Bonferroni correction found serial positions one ($M = .723$; $SE = .033$) and two ($M = .737$; $SE = .038$) did not significantly differ from each other ($p = 1.000$), but both were significantly lower than the proportion of recall at position three ($M = .840$; $SE = .023$, all $ps < .05$). The interaction between the two factors were marginally significant, $F(2,58) = 2.963$, $p = .060$, $\eta p^2 = .093$. This was attributed to a higher recall accuracy in the adult version of the task at the first serial position, $t(29) = 2.971$, $p = .006$. The comparison of positions two and three showed no difference in accuracy between the two experiments (position two: $t(29) = .154$, $p = .879$; position three: $t(29) = .290$, $p = .774$).

Similar findings were evident when comparing the RTs recorded across the two different versions of the task. There were no differences in RT as a function of experiment version, $F(1,28) = 2.012$, $p = .167$, $\eta p^2 = .067$, but there was an effect of serial position, $F(2,56) = 7.871$, $p = .001$, $\eta p^2 = .219$. Multiple pairwise comparisons revealed adult participants were significantly quicker at recalling positions one ($M = 1.513$; $SE = .133$) and three ($M = 1.561$; $SE = .173$) in comparison to position two ($M = 1.970$; $SE = .158$, all $ps < .05$). The interaction between the two factors was also non-significant, $F(2,56) = .978$, $p = .383$, $\eta p^2 = .034$.

Due to the adults' performance showing no difference between the two experimental versions, the data collected from the children's version of the task was used when comparing the adults with the children's performance. Two 3 (serial position: position one vs. position two vs. position three) x 4 (age: Year 1 vs. Year 3 vs. Year 5 vs. Adults) mixed factor ANOVAs analysing proportion of correct recall and mean RT was carried out. Age-related differences were identified using posthoc tests with a Bonferroni correction, reported in Table 5.2. The analyses revealed a significant age-related increase in the correct proportion of recalled target items, $F(3,161) = 46.014$, $p = .001$, $\eta p^2 = .466$, with a significant increase in recall at all age points (all $ps < .05$). To accompany accuracy, participants got quicker at recalling target memory items as a function of age, $F(3,138) = 47.329$, $p = .001$, $\eta p^2 = .507$, with significant reduction between all age groups (all $ps < .05$).

Table 5.2: *The mean proportion of correct recall and mean RT as a function of age.*

	Year 1	Year 3	Year 5	Adults
Mean proportion of recall	.354 (.021)	.442 (.022)	.528 (.023)	.740 (.027)
Mean correct RT (s)	6.78 (.304)	4.23 (.300)	2.87 (.304)	1.775 (.338)

Serial position was also analysed in terms of accuracy and RT. The accuracy measure revealed a significant effect of serial position, $F(2,316) = 33.387$, $p = .001$, $\eta p^2 = .174$ (Figure 5.3A). Multiple pairwise comparisons using a Bonferroni correction reported an increase in accuracy between positions one ($M = .430$; $SE = .017$), two ($M = .513$; $SE = .017$) and three ($M = .606$; $SE = .017$, all $ps < .001$). However, the interaction between serial position and age, $F(6,316) = .692$, $p = .657$, $\eta p^2 = .013$ revealed that despite all age groups showing an effect of serial position (all $ps < .05$), the serial position effect was allocated to different positions. Only Year 1 showed the exact main effect. Years 3, 5 and adults showed no difference between positions one and two (all $ps > .05$), but position three produced significantly higher proportion of recall than the other two positions (all $ps < .05$).

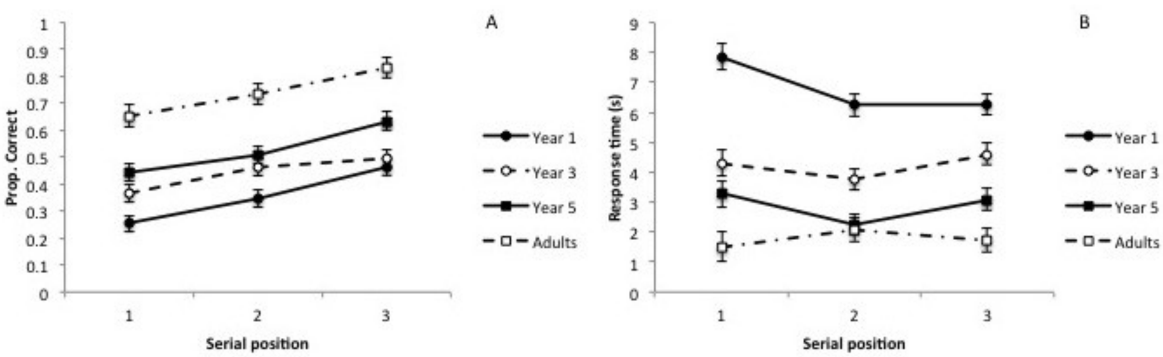

Figure 5.3: Proportion of recall (A) and response time (RT) data (B) as a function of serial position and age. Error bars represent one standard error from the mean.

The same analysis for RT also showed a significant effect of serial position, $F(2,276) = 4.520$, $p = .012$, $\eta p^2 = .032$ (Figure 5.3B). Serial position one produced the slowest RT ($M = 4.239$; $SE = .227$) in comparison to position two ($M = 3.588$; $SE = .188$, $p = .014$). Position three ($M = 3.927$; $SE = .183$) did not differ from either positions (both $ps > .05$). The significant interaction between the two factors, $F(6,276) = 3.470$, $p = .003$, $\eta p^2 = .070$, was attributed to the four different age groups producing different patterns of RT across the three serial positions. Years 1, 5 and adults produced significant effects of serial position (Year 1: $F(2,72) = 4.734$, $p = .012$, $\eta p^2 = .116$; Year 5: $F(2,72) = 5.841$, $p = .004$, $\eta p^2 = .140$; Adults: $F(2,58) = 4.712$, $p = .013$, $\eta p^2 = .040$), whilst Year 3 produced equivalent levels of RT across the three positions, $F(2,74) = 1.955$, $p = .149$, $\eta p^2 = .050$.

5.3.3 The inter-relations between WMC and independent measures of SM

Table 5.3 reports the zero-order and partial correlations controlling for age of all age groups involved between RT and accuracy measures from the delayed cued recall task and WMC (derived from listening span performance). This analysis indicated that individuals with a higher WMC produced a quicker RT and a higher recall of items in the delayed task. When age was partialled out of the correlational analysis, the inter-relations remained with the exception to the non-significant correlation between the accuracy and RT measures. This was investigated further by looking at the zero-order correlations for each age group. None of these correlations were significant (all $ps < .05$), however, it was apparent that the relation between accuracy and RT was positive in Year 1, whilst the relations between the other three groups were negative relationships growing in strength.

Table 5.3: The correlational analysis between WMC and the delayed cued recall accuracy and response time (RT) measures. The lower triangle reports the partial correlations controlling for age.

	1.	2.	3.
1. Delayed cued recall RT	-	-.451***	-.727***
2. Delayed cued recall Acc.	-.016	-	.588***
3. WMC	-.420***	.167*	-

Note. RT=Response Time; Acc=Accuracy; WMC=Working Memory Capacity. $p < .05^*$ $p < .01^{**}$ $p < .001^{***}$

5.4 Discussion

The aim of Chapter 5 was to attempt to provide an explanation as to why children find it so difficult to access information that is not immediately accessible. As defined by Unsworth and Engle (2007b), SM is a domain-general system that is dependent on the use of contextual cue-dependent search processes to retrieve target information from a more durable, long-term store. Individual differences lie in the ability to internally generate effective, unique cues that de-limit the search set, reducing the production of intrusions and interference. Two tasks were developed to provide two different indexes of SM use. The cued listening span task provided the opportunity to assess the accessibility of memory items believed to be forgotten, and the effectiveness of different types of cues that facilitate such accessibility. The delayed cued recall task provided a developmental trajectory of when children can systematically use cues to retrieve information from a longer-term store. The inter-relations between WMC and the delayed cued recall task were then used to ascertain whether the new independent SM tasks were tapping into cognitive commonalities with WMC.

The cued listening span task provided evidence of age-related increases in SM use, but also the effectiveness of contextual cues in the facilitation of SM use in adults and children. The baseline measures taken from the listening span task showed an age-related increase in WMC. Performance on WMC tasks are driven by SM, due to storage items being displaced into SM from PM as a consequence of attention being allocated to the processing element of the task. Following Unsworth and Engle (2007b), the current findings are reflective of a developmental increase in children's ability to retrieve information from SM. However, the key question was the accessibility of memory items and how different cues facilitate the search process and retrieval from SM. Firstly, children as young as five- years old were able to access information that would normally be assumed to be inaccessible. This implies that the target memory representations are being encoded and stored in SM, but highlights the potential issue that children are unable to generate sufficient, internal contextual cues to retrieve the memory items.

Secondly, the use of external cues that were semantically related to the whole sentence were more beneficial than a cue solely specific to the target memory representation. All age groups showed the sentence cue condition to be more effective than the word cue condition, indicating that adults and children use contextually relevant information to retrieve information. This extends the work by Towse et al. (2010) who found children aged seven- to 11 years were influenced by reconstructive processes when completing complex span tasks. The cued listening span task showed even younger children are able to use the contextual "gist" of a sentence to access target information (Cowan et al., 2003; Towse et al., 2008a). Because the sentence cue was taken from the sentence itself, it was part of the encoding procedure. Thus, the greater the association between the external cue and the response, the greater the focus of the search set and the higher the probability of selecting the correct item (Unsworth, 2009). In contrast, the word cue was isolated, and therefore held no contextual relevance that an individual may have been able to use to facilitate retrieval. This demonstrated a cooperative relationship between the processing and storage elements, as opposed to a competitive relationship (Daneman & Carpenter, 1980). This converges with Osaka et al. (2002), who suggested that the encoding of core words from the sentence enhances the active search and recall of storage items in reading span tasks.

Schroeder et al. (2012) made the valid suggestion though that individuals are able to use contextual information in order to retain target items, but the context has to be unique. Therefore, if the processing element of the task had been a continuous story (as tested in Schroeder et al.'s experiments) there may have been a reduction in adults' and children's recall performance. This helps explain why Unsworth and Engle (2007b) suggested the requirement to generate a variety of cues that de-limit the search set as much as possible. This ranges from global, very general cues to very specific information associated with just the target. Individuals have to combine the continuum of cues to provide a unique context in order to retrieve the target information.

As part of understanding complex span performance, a form of encoding specificity (Tulving & Thomson, 1973) could have contributed to the differences in the effectiveness of cues. The extent to which a cue is effective is dependent on the similarity of the contextual elements at encoding and recall. The word-specific cue was outside the context that the target word was presented in and may have caused conflict with individuals own internally generated cues associated with the target item, accounting for its diminished effectiveness in comparison to the sentence cues. Therefore, individuals have to relieve the internal conflict and successfully combine the external and internal contextual cues to facilitate the retrieval of items from SM.

The baseline measures of WMC were taken from the cued listening span task. Participants from Year 5 and adults who were allocated to a cue condition showed increased WMC in comparison to the participants in the no cue condition. It is possible that coincidentally those participants in the cued conditions had a higher WMC before the administration of cues. However, it seems more plausible that the exposure to cues induced strategies, for example encoding the gist of the sentence or attaching specific associations to the target memory item. Participants realised how they could enhance their recall, and thus their SM use. Therefore, older children are able to retrieve target information from the longer-term store without the explicit administration of external cues.

The delayed cued recall task was used to evaluate the developing efficiency of the retrieval of items from SM from five- years through to adulthood. Originally, Miyake and Friedman (2004) used a delayed cued retrieval task to find it was the only task to substantially reduce the correlation between reading span and cognitive abilities. Their interpretation was attention-mediated abilities are necessary to reactivate and retrieve target memories from long-term memory. The modified version of this task for the current experiment was believed to be an appropriate task for children, presenting them with fewer memory items to remember, reducing the cognitive demand of the task that free recall had caused. This should provide a better exploration of a developmental trajectory of children's ability to use SM. This task was believed to be reliant on this mechanism, due to the use of a distractor tasks and the requirement of semantic features of words (Craik & Levy, 1970), neither of which were found to affect PM. Firstly, adults took part in two versions of the delayed cued recall task: the new children's version and the original task stimuli used by Miyake and Friedman (2004). Adults demonstrated equivalent levels of accuracy and RT despite the adult task using more complex and less frequent semantic associations in comparison to the children's version. This was not expected, as high frequency words are recalled more accurately then low frequency words (Raymond, 1969). One would assume that the words in the children's task had a higher frequency than the words in the adults' task. This infers that the associations surrounding a memory item in SM does not necessarily affect retrieval, but it is the retrieval process within SM that contributes to the efficient running of this system.

Analysis of the delayed cued recall task, including all four age groups showed systematic differences in performance. As age increased, participants were able to recall more items after the distractor activity. However, five- to six-year olds were only able to successfully recall 35.4% of memoranda, increasing to 52.8% by nine- to ten-years, whilst the adults showed a higher accuracy of 74.0%. In line with this, the age-related decrease in RT must not be masked by the amount of time the search and retrieval processes took in successful recall. The youngest children took up to 7.86s to retrieve target information, which reached 1.5s in adults. This suggests that the use of SM is not only hard for the oldest children age, but is also a slow process for them to engage in. This brings into question the recoverability, and thus accessibility, of memory items within SM. Young children are heavily reliant on the retention of immediate information, and find it very difficult to engage in the controlled search and retrieval process, potentially due to the SM items having weaker target representations. This is attributed to differences in encoding processes, for example rehearsal or elaboration. As mentioned previously, Engel de Abreu et al. (2010) suggested that a developmental shift in PM and SM use should occur at the age of seven, when children begin to show evidence of rehearsal (Flavell et al., 1966; Gathercole et al., 1994). However, in Chapter 2, despite the expected developmental change, children did not demonstrate any use of this i.e. enhanced primacy recall at the slower presentation rate. The current work is limited as it was not recorded as to whether children were using rehearsal, nor was it used as a manipulation. Therefore, despite the evidence indicating children are becoming more proficient in carrying out the controlled processes, future research needs to consider directly investigating whether those children who engaged in rehearsal increased their chances of retrieval processes from recall.

The current use of the delayed cued recall task is the first step in investigating whether children are able to focus their recall through external cues and retrieve target information. To follow, future work needs to consider taking a baseline measure of recall without the external cues to determine the extent to which this task is reflective of developmental differences in retrieval efficiency. In addition, this task only uses semantic associations. Similar to the recall reconstruction hypothesis, it is believed that these findings are not just specific to semantic information as external information (Cowan et al., 2003; Towse et al., 2008a, 2010). It is plausible that as a feature of retrieval, performance on cued recall tasks regardless of the types of cues should predict WMC. It would be interesting to compare semantic cues with other types of cues, for example colour, within the delayed cued recall task context to investigate this statement.

Taking into consideration the results discussed above, it sheds light on why children produce relatively weak primacy effects in comparison to their robust recency effects, and in turn low SM estimates. The ability to retrieve target items successfully from SM is an attentionally demanding process. Applied to a free recall perspective, participants have to generate their own internal cues, which is one of the most attention demanding aspects of retrieval (Guez & Naveh-Benjamin, 2006) as there is no environmental support for the participants to use in order to retrieve SM items. List items are shown at a relatively fast pace, of which they have to sustain their attention throughout the whole presentation, with very little or no possibility of using maintenance strategies. Therefore, it is possible that the task and the search and retrieval process required to use SM is too much of a demanding activity for the children to carry out. It was a very demanding process for children to successfully retrieve one target memory item from one memory system, and shows why the free recall findings should not have been such a surprise in comparison to adults' performance.

There is the possibility that performance on this task may be explained by word association effects facilitated by the semantic word cues as opposed to retrieval from SM. Simply put, word associations are words that arise in an individual's mind when presented with another word or conceptual category (for example, you hear the word table and you immediately think chair). However, this was considered as part of the task design and how the stimuli were chosen. Despite all target words belonging to a category, they should not have been the first words that came to mind, filtered by the collection of pilot data (see section 5.2.2). The careful selection of stimuli when designing the tasks substantially reduced the potential confound of participants using word associations instead of retrieving memory representations accurately. Another issue that may be a consequence of selecting the stimuli in such a manner is that this removes high frequency words that were previously used as stimuli in the free recall paradigms in Chapters 2 to 4. This may mean that the words that were used were too low frequency and too hard for children of the lowest age range. However, this was also considered and the words chosen from Morrison et al. (1997) were appropriate for the age range chosen. Combined, the stimulus set provides a reliable opportunity to assess whether children can retrieve memory representations that are not immediately accessible, but retrievable from a longer-term construct.

It was also important to assess whether the delayed cued recall task was linked to WMC, taken from the baseline performance on the cued listening span task, believed to be the recall of information outside their focus of attention, or SM. It was evident that even when age was controlled for, the delayed cued recall and WMC tasks shared cognitive commonalities. Specifically, those individuals with higher WMC were quicker at retrieving SM items but also recalled more target memory representations. Unsworth and Engle (2006a, 2007b) have stated that SM is the driving force in complex span tasks, and the adult and children data supports this statement. Interestingly, the correlation between RT and accuracy was lost when age was controlled for. Whilst Year 5 and adults were demonstrating the expected negative correlation, this was not apparent in youngest age range. The trend towards a positive correlation in the Year 1 data between accuracy and RT suggests that the longer participants took in trying to retrieve the target item, the more successful they were, which was the opposite to all other age groups. This is an additional indication of how difficult the younger children found this task.

Thus far the data have shown that children are able to recall items in experiments that are more prone to involving SM, and reducing PM use. It suggests that there are a variety of sources that can be used as cues to access and retrieve information from working memory, which children as young as five- years are able to do. When forced to not rely on the active maintenance of items in PM, but use contextual information, children are able to retrieve accurate memory representations from a longer-term store. As initially predicted, those items that are not recalled are actually still accessible. Furthermore, children are able to combine external and internal cues sufficiently to demonstrate developmental improvements in the retrieval of SM items up to adulthood. However, the lower than expected accuracy levels of children provides insight into why children show limited SM use in free recall tasks. It also shows that for children reaching the end of primary school, the processes required to use SM still need time to develop through secondary school to reach the level of adults using the same cognitive construct. As far as the author of this thesis is aware, no one has adopted independent measures such as these to assess SM. This has contributed to research field's knowledge base by not only showing increases in SM estimates across childhood, but also the developing mechanisms that underpin this system.

Working memory is well established as a key cognitive contributor in academic attainment, therefore it is crucial to not only understand how the cognitive construct develops, but also its linked to higher-order cognition. Chapters 2-5 have investigated the development of PM and SM through childhood. Due to the variability of SM as a greater predictor of WMC in children, the next point of investigation was to address whether the variance surrounding SM was also involved in academic attainment, in this case, reading comprehension. Chapter 6 adopted a new task to address SM use, vocabulary measures and reading comprehension, in order to address whether the retrieval processes from SM are involved in the ability to process and maintain information to create a meaningful representation of text.

Chapter 6

Individual differences in the use of cued recall paradigms: investigating the role of retrieval abilities and reading comprehension

6.1 Experiment 5: Introduction

Reading comprehension requires the ability to process the semantic and syntactic relations amongst words, phrases and sentences. The reader must be able to maintain or store the information and use it to disambiguate the text and create a meaningful representation (Daneman & Carpenter, 1980; Daneman & Merikle, 1996). Variation in working memory has been used to explain individual differences in children's reading comprehension, above and beyond other predictors such as decoding, word recognition, and vocabulary knowledge (Swanson & Berninger, 1995; Yuill et al., 1989). The current chapter continues the investigation into the development of retrieval based processes within SM, using an additional task, the conceptual span task. In addition to the delayed cued recall task, this will examine whether individual differences in the ability to carry out controlled contextual, cue-dependent search processes contribute to the relationship between working memory and reading comprehension.

The conceptual span task was originally used by Haarmann et al. (2003) as an index of semantic short-term memory capacity and its contribution to online sentence comprehension. This is a cue based free recall task. Participants are given a list of nine words that incorporates words from three semantic categories. At recall, participants are given one of the semantic categories as a cue and they have to try and recall the items specifically related to that category. Based on three experiments, Haarmann et al. (2003) found that conceptual span correlated highly with reading comprehension, more so than conventional measures of simple and complex span tasks (word span and reading span). Haarmann et al. provided an insightful interpretation of the conceptual span task as an index of semantic short-term memory, maintaining concepts in the focus of attention (Cowan, 2001), allowing access to stored semantic representations and the relationships between them. However, there may be an alternative explanation, whereby the cue based retrieval processes necessary to be successful at working memory tasks also contribute to performance on the conceptual span task. This is moving the interpretation away from an immediate, highly accessible memory system such as PM or the focus of attention, and suggesting retrieval from a long-term store, such as SM.

The conceptual span task follows a similar framework to the delayed cued recall task, in regards to retrieving target memory representations. The original task by Miyake and Friedman (2004) was described as an index of an attention-mediated ability to use retrieval cues to reactivate target memory items. In Experiment 4, the three children groups were able to retrieve target information to increasing extents, but the oldest nine- to ten-year olds were still unable to use such processes to the level of adults. The conceptual span task within this context is believed to require the same underlying processes, but within a free recall paradigm. Previous attempts have been made in this thesis to improve children's recall of items from the beginning of the list, a reflection of their search and retrieval abilities from SM, but with no success. External cues were used to investigate individual differences in the ability to combine internal and external cues, enhancing the retrieval of target memory representations. Therefore, the conceptual span task will be compared with the re-use of the delayed cued recall task and whether the two tasks share the use of cognitive processes that underlie children's developing use of SM and functioning of working memory.

The errors made by the adults and children were used as an additional line of investigation to try and understand the development of controlled search and retrieval processes in children. Prior list intrusions (PLIs) were of particular interest. Unsworth and colleagues (Unsworth, 2007, 2009; Unsworth & Engle, 2007b) have suggested that PLIs are an indication of inefficient search and retrieval processes from long-term memory. Adults with low WMC were identified as producing a lower level of recall, but a greater number of intrusions. This was attributed to the use of noisier contextual cues, making it much harder to de-limit the search set to the target items that need to be retrieved. Errors such as PLIs are expected as a consequence of proactive interference building up through a task, leading to inefficient retrieval (Wixted & Rohrer, 1993). This type of error is an indication that long-term memory is being used. However, of specific interest is whether there is an age-related decline in the number of PLIs produced across the age range chosen. This would indicate children's growing efficiency in carrying out the retrieval processes efficiently when faced with the competitive search and retrieval processes.

Haarmann et al.'s conceptual span task was believed to have predictive power of complex cognition above and beyond simple and complex span tasks. In their third experiment the authors used a non-clustered (stimuli randomly placed in a list) and a clustered version (stimuli organised by semantic category) of the conceptual span task and found both versions had a strong predictive power of language comprehension tasks. Kane and Miyake (2007) assessed the validity of Haarmann et al.'s task to report that the task and other cued-recall tests (colour, the first letter of a word, or the first vowel of a word as a recall cue) could not predict additional variance in complex cognitive task performance beyond short-term memory tasks. However, Kane and Miyake (2007) only used a clustered version of the task, grouped by an attribute (semantic category, or colour). It is not entirely clear why the difference in findings may have occurred. One possibility is the difference in the size of the clusters used. Whilst the original non-clustered conceptual span task incorporated three items per semantic category, this was increased to four items in the clustered version of the task. The clusters in Kane and Miyake's conceptual span task consisted of three- to five-words. However, this does not seem an obvious reason as to why predictability of cluster size could differentiate the results from the two studies. In order to further understand the experimental design of the conceptual span task, in the current experiment, both versions of the task were administered to adults. The comparison of cluster sizes were kept the same (three-items) between the two versions of the task to determine whether the organisation of information, as opposed to the size of the cluster was impacting any differences in their relationship with WMC.

A strong link between working memory and reading comprehension in children has been reported in several studies. Leather and Henry (1994) showed working memory to account for significant variance in seven- to eight-year olds comprehension skill when controlling for phonological awareness and short-term memory span, whilst Engle et al. (1991) used the age range seven- to 12-years to obtain strong correlations between working memory span and text comprehension. Four- to five-year olds (Florit et al., 2009) and eight- to 11-year olds (Cain et al., 2004) showed working memory significantly contributed to reading comprehension, when word reading and verbal ability were controlled for. Despite differences in details, these studies converge by taking into account multiple variables related to decoding and linguistic comprehension, emphasising the role of WMC as a direct contributor to reading comprehension.

Depending on the theoretical approach taken the functional role of working memory in reading comprehension is explained in different ways. Firstly, the multifaceted approach (Baddeley & Hitch, 1974; Shah & Miyake, 1996), proposed the domain-specificity of factors are what drives the relation between working memory and reading comprehension. This fits with the explanation that verbal working memory tasks and reading comprehension tasks are linked as a consequence of both drawing on the verbal domain. In contrast, the resource sharing model (Daneman & Carpenter, 1980; Just & Carpenter, 1992) assumed that processing and storage operations compete for a limited pool of working memory resources. Therefore, the link between working memory and reading comprehension is attributed to individual differences in how resources were allocated to processing and storage activity. The more recent theoretical accounts are still based on the concept that memory items are actively and continuously maintained during performance on complex span tasks. Thus, it is the notion of active maintenance of memory items that plays a central role in working memory span tasks, and in turn theoretical accounts (e.g. the episodic buffer, Baddeley, 2000; the focus of attention, Cowan, 1995; controlled attention, Engle et al., 1999).

The current thesis argues that not all memory items can be actively maintained, and thus out of immediate focus. This is directly applied to investigate how SM is used to complete complex span tasks. Individuals have to retrieve information that cannot be actively maintained due to the processing of new, incoming information. This chapter proposes that the involvement of working memory in reading comprehension can be explained from a retrieval based perspective. Conceptually similar to how complex span performance is explained by PM and SM, the initial words at the beginning of the sentence are actively maintained in PM. However, due to incoming information that requires processing, the information from the beginning of the sentence is displaced into SM and requires cue-dependent search processes to retrieve the target information. As demonstrated in Figure, 2.10, variability in children's ability to retrieve SM items was a unique predictor of WMC in comparison to PM. Moreover, the delayed cued recall task correlated with WMC (section 5.3), suggesting retrieval abilities are a contributor to the ability to use working memory proficiently. Therefore, the findings of this thesis have enabled the conceptualisation that the ability to access and retrieve words and their meanings from a longer-term store could significantly contribute to children's understanding of text. Taken together, it suggests the relationship between working memory and reading comprehension is mediated by participants' ability to pursue controlled, contextual cue-dependent search processes and retrieval.

As part of understanding the link between working memory and reading comprehension, other linguistic skills should be considered. The knowledge of word meanings is critical for reading comprehension and has been established in both adults and children (Bast & Reitsma, 1998; Carroll, 1993; Thorndike, 1973). Vocabulary is considered as long-term knowledge that needs to be retrieved in order for an individual to construct an understanding of what the text means. A large vocabulary provides an increased opportunity for orderly searches of memory (Wilson & Anderson, 1986), whereby word forms are readily identified and word meanings are easily accessed (Verhoeven & van Leeuwe, 2008). This is in line with the retrieval based approach as proposed in the current chapter; the act of accessing and retrieving word meanings from long-term memory provides the idea that SM may contribute to the controlled search process is order to retrieve the correct semantic representation of the word being read.

Based on the research cited, it is difficult to determine which is a greater predictor of reading comprehension: vocabulary or working memory. Text comprehension would be very difficult without knowledge of individual word meanings. Therefore, vocabulary is continuously linked to measures of reading, and comprehension, and believed to be one of the best predictors of reading comprehension ability (Ouellette, 2006). Thus, the next question is what is the nature of the relationship between working memory, vocabulary and reading comprehension from a retrieval-based perspective? It has been suggested that working memory differences disappear if verbal intelligence is controlled for (Stothard & Hulme, 1996). This implies that the role of working memory is mediated by verbal ability (Nation et al., 1999). Nation et al. (1999) argued that poor comprehenders have a semantic weakness that restricts their ability to store verbal information in short-term memory and impairs performance on verbal complex span tasks. This was further supported by findings that no differences were found between good and poor comprehenders in spatial complex span tasks. These data indicate memory deficits associated with poor reading comprehension was mediated by verbal abilities. On the other hand, work has shown what working memory is a direct predictor of reading comprehension after controlling for variables related to language comprehension (e.g. Leather & Henry, 1994). Cain et al. (2004) and Florit et al. (2009) found a direct relationship between verbal working memory tasks and reading comprehension after controlling for verbal skills, including vocabulary knowledge. The authors concluded that verbal skills alone cannot account entirely for the relationship between reading comprehension and working memory, which is a specific contributor to reading comprehension. The current experiment provides the opportunity to assess whether working memory is playing a mediating role or acting as a unique predictor in reading comprehension, indexed by the measure of reading comprehension and the listening span task. By including the conceptual span task and the delayed cued recall task measures it provides the opportunity to ascertain whether retrieval ability from a long-term store helps explain the relationship between vocabulary, working memory and reading comprehension.

The use of a vocabulary measure may also provide additional insight into whether the delayed cued recall and conceptual span tasks are also mediated by children's vocabulary knowledge. It is possible that individuals with a greater vocabulary knowledge have greater access to memory representations that need to be retrieved in order to be successful at the tasks under question. In the original use of the conceptual span task by Haarmann et al. (2003) there was no consideration of how long-term vocabulary knowledge affected individual differences of what this task is measuring. Miyake and Friedman (2004) incorporated a word knowledge task into their suite of tasks to understand the relationship between reading span tasks and complex cognitive abilities. Despite having significant correlations with reading span score, it did not have an effect on the relationship between reading span and cognitive abilities. It is possible that long-term vocabulary knowledge and retrieval processes work in combination in how adults and children complete the task. The question is whether vocabulary is a stronger influence than children's ability to retrieve target information from SM.

In summary, this experiment included two measures of retrieval processes (conceptual span and delayed cued recall tasks), a measure of WMC (listening span task), reading accuracy and comprehension (YARC) and vocabulary (BPVS) to determine their predictive value in reading comprehension. The age range was reduced to seven- to ten-year olds. Five- to six-year olds found the delayed cued recall task very difficult, producing a low accuracy and slow RT, demonstrated in Experiment 4. Therefore, it was thought the conceptual span task would be too difficult for the younger children. In addition, the youngest age used in the literature cited (Cain et al., 2004; Engle et al., 1991; Leather and Henry, 1994) is seven-years old. This provided a theoretical basis for using the selected age range and provided the opportunity for the current experiment to contribute to understanding the developmental link between reading comprehension and working memory.The inter-relations between the delayed cued recall task, the conceptual span task and WMC were assessed to support the findings of Experiment 4. The introduction of reading comprehension measures provides the opportunity to explore whether SM retrieval processes are linked to reading comprehension, i.e. those individuals who are better able to use SM to retrieve target information would have greater reading comprehension ability. By collecting an index of vocabulary, it can be ascertained whether long-term knowledge of vocabulary is a mediating factor in the retrieval processes proposed to contribute to reading comprehension ability.

6.2 Method

6.2.1 Participants

The first part of this experiment comprised of 104 children participants. Parental consent was gained for two children age groups: seven- to eight-year olds (Year 3; N = 51, M = 8:01 years, range: 7:03-8:10 years, 28 female), and nine- to ten-year olds (Year 5; N = 53, M = 9:07, range: 9:00-10:07 years, 27 female). Forty-five undergraduate students were recruited from Lancaster University (M = 19:03 years, range: 18:06 - 20:08 years, 35 female)

6.2.2 Materials

All tasks were once again developed on PsychoPy software (Pierce, 2007, 2009), carried out on a 15-inch Macbook laptop. The corpus of stimuli used in Experiment 4 (section 5.2.2), was extended to 43 semantic categories taken from Overschelde et al., (2004) with 228 one- or two-syllable concrete nouns (Appendix V).

6.2.3 Design and Procedure

All participants took part in the listening span, delayed cued recall and non-clustered conceptual span tasks. In addition, adults took part in the clustered version of the conceptual span task. Children also completed vocabulary and reading comprehension measures. Children were tested in two sessions lasting approximately 25 minutes each. One session included all the memory measures, the other was the reading and vocabulary tasks, all counter-balanced accordingly. All children were tested individually in a quiet classroom setting. The adults completed just one research session lasting approximately 40 minutes, carried out in a laboratory setting in the Psychology Department, Lancaster University.

6.2.4 Memory tasks

The conceptual span task used nine-item lists that incorporated three semantic categories containing three concrete nouns for each category (Figure 6.1). The task consisted of a total of twelve trials, broken down into two blocks of six trials each. Two versions of the task were used: non-clustered and clustered. In the non-clustered version of the task, all items were presented in a random order, whilst the clustered version of the task involved items from the same category all being placed together. Stimuli were recorded in a female voice presented at a rate of one word per second with a 250ms ISI between stimuli. After listening to the nine words, participants were given one of the three semantic category names as a recall cue. Participants had to try and recall all three-items from the target category in any order they wished. Task accuracy was recorded as a function of serial position and recall order.

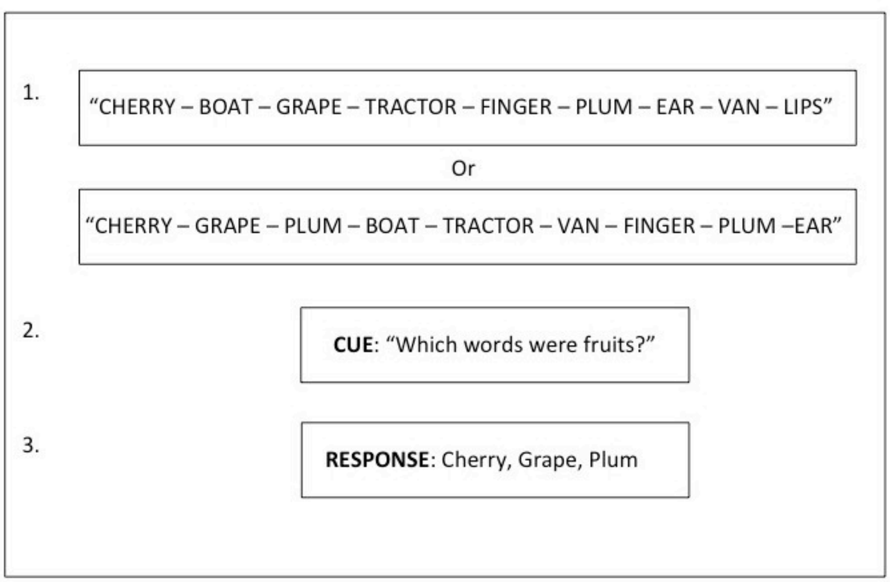

Figure 6.1: A schematic of the clustered and non-clustered versions of the conceptual span task.

The delayed cued recall task was the same task as used previously (section 5.2.5), and the listening span task was the same sentence completion task as used in section 3.2.5. An additional list length of six items was added to the adult version of the task. The additional sentences and memory items were taken from Towse et al. (1998a).

6.2.5 Reading comprehension measures

The York Assessment of Reading Comprehension (YARC, Snowling et al., 2009) was used to assess children's reading comprehension. All children read an age-appropriate reading passage and were then asked eight questions about the information read. If they scored five or more they read a second passage at a higher level. If they scored four or below participants read the passage at a lower level. The children read the stories out loud, generating an accuracy score. Their answers to the comprehension questions generated a reading comprehension score.

The British Picture Vocabulary Scale III (BPVS, Dunn & Dunn 2009) assessed the children's vocabulary level. Age-appropriate materials were used for each age groups, using the set of items on the performance record and corresponded to the individuals age. The basal score was set when an individual made no more than one error in a set. If an individual made more than one error, the experimenter administered the preceding set of items. Once the basal score was established the experimenter continued with the test until a ceiling for an individual was established. A ceiling score was set as eight or more errors within a set of 12 items. A raw score was calculated by subtracting the number of the ceiling item (the last item in the ceiling set) by the total number of errors made by the individual. This provides a raw vocabulary score.

6.3 Results

This section aimed to investigate the conceptual span task as an additional measure of SM and its relation to WMC and reading comprehension. In order to provide a comprehensive review of the analyses, the results section was split into five sections. Sections one to three analysed the serial position effects of the conceptual span tasks. First, performance on the conceptual span task was compared to the free recall performance from Experiment 3 section 4.3.1. This was tested to ascertain whether supported cued recall facilitated the retrieval of pre-recency memory items. To follow, adults performance on the clustered and non-clustered versions of the conceptual span task were analysed, and their relation to WMC was examined. Next, the different errors made by participants were categorised and analysed as an indication of inefficient search and retrieval processes from SM. The delayed cued recall task was analysed separately with the aim to replicate the age-related increases in recall from Experiment 4. In the final section, all children's memory measures were combined with their vocabulary and reading comprehension scores. Using correlational and regression analyses, this aimed to investigate the extent to which vocabulary, working memory and retrieval abilities contributed to individual differences in reading comprehension.

6.3.1 Conceptual span task

The serial position effects were analysed to specifically examine the primacy effect in adults and children. Because participants were instructed to recall three target memory items that were randomly positioned, the most useful performance metric on this task was to calculate the proportion of correct recall instead of PR. In order to ascertain whether the primacy effect was masked by the cues elevating the retrieval of pre-recency items, the proportion of recall of the conceptual span task was compared to the proportion of correct recall from the auditory free recall performance from Experiment 3, section 4.3.1. This was used because it was the same presentation modality, and used the same age groups.

Age-related and serial position effects were analysed in a 9 (serial position: positions one to nine) x 3 (age: Year 3 vs. Year 5 vs. Adults) mixed factor ANOVA. The significant effect of age, $F(2,33) = 32.789$, $p < .001$, $\eta p^2 = .665$, and a posthoc test using a Bonferroni correction revealed that both children groups did not differ from each other (Year 3: $M = .371$; $SE = .022$; Year 5: $M = .421$; $SE = .022$, $p = .363$). However, all children produced significantly lower proportions of recall in comparison to adults (both $ps < .001$). A significant effect of serial position was also evident, $F(8,264) = 36.144$, $p < .001$, $\eta p^2 = .523$. Multiple pairwise comparisons showed no differences between positions one to six (range: .294-.382), thus eliminating any form of a primacy effect. In contrast, a recency effect was observed for the last three serial positions (range =.507-.862), to the point where positions eight and nine produced a higher proportion of correct recall than all other positions (all $ps < .05$). The interaction between the two factors was non-significant, $F(16,264) = .655$, $p = .836$, $\eta p^2 = .038$, thus indicating all age groups performed in a similar manner (Figure 6.2A).

The examination of the primacy effect was further substantiated by the comparison of the serial position effects with the free recall performance from section 4.3.1. The lists were split into three sections: beginning, middle and end. The free recall data used ten-item lists, therefore the beginning section used serial positions one to three from both tasks, and the end section was the last three serial positions of each list (conceptual span: positions seven to nine; free recall: positions eight to ten). For the middle section positions four to six were taken from the conceptual span and positions five to seven from the free recall tasks. Therefore, serial position four was not used within the analysis, but this was not a problem as it did not significantly differ from positions three and five.

In order to determine task differences in performance a 2 (experiment type: free recall vs. conceptual span) x 3 (section: beginning vs. middle vs. end) x 3 (serial position:

position one vs. position two vs. position three) x 3 (age: Year 3 vs. Year 5 vs. Adults) mixed factor ANOVA was carried out. The main effects were dissected further using the same posthoc analysis previously described. An age-related increase was evident, $F(2,39) = 22.823$, $p < .001$, $\eta p^2 = .539$. The children groups did not differ from each other ($p = .182$), but both groups recall was significantly lower than the adults performance (both $ps < .001$). Interestingly though, there were no significant interactions with age (all $ps > .05$), and therefore the findings described above were consistent across all age groups.

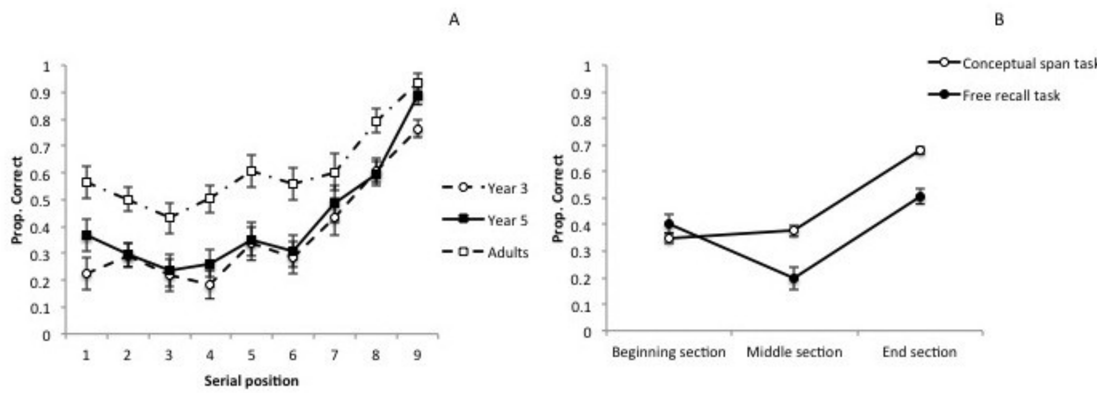

Figure 6.2: The proportion of correct recall as a function of serial position and age (A); The proportion of correct recall as a function of task section and experiment version (B). Error bars represent one standard error from the mean.

A significant effect of serial position was also evident, $F(2,78) = 8.285$, $p = .001$, $\eta p^2 = .175$. The interaction between serial position and section, $F(4,156) = 14.993$, $p < .001$, $\eta p^2 = .278$, was reflective of the traditional U-shaped serial position curve The beginning section showed a decrease in recall as a function of serial position, reflective of the primacy effect. The proportion of recall within the middle section was relatively stable with a rise at the final position of this section; whilst the end section showed the expected rise in a recency effect.

Significant effects of experiment type, $F(1,39) = 13.185$, $p = .001$, $\eta p^2 = .253$ and section, $F(2,78) = 71.851$, $p < .001$, $\eta p^2 = .648$, were evident. The conceptual span task generated a greater proportion of total recall ($M = .467$; $SE = .012$) than the free recall task ($M = .369$; $SE = .024$). Not surprisingly, the end section generated the largest proportion of recall ($M = .593$; $SE = .017$), followed by the beginning section ($M = .375$; $SE = .019$), and the middle section produced the lowest level of recall ($M = .287$; $SE = .024$; all $ps < .01$). Further, the significant interaction between section and experiment type, $F(2,78) = 12.878$, $p < .001$, $\eta p^2 = .248$, highlighted that whilst there were no differences in the beginning section between the two experiment types, $F(1,39) = 2.064$, $p = .159$, $\eta p^2 = .050$, the conceptual span task produced greater recall in the middle, $F(1,39) = 13.654$, $p = .001$, $\eta p^2 = .259$, and end sections, $F(1,39) = 26.544$, $p < .001$, $\eta p^2 = .405$ (Figure 6.2B).

6.3.2 The comparison of the clustered and non-clustered versions of the conceptual span task

Adult participants took part in the two different versions of the conceptual span task: the non-clustered and clustered conceptual span tasks. The comparison of the two versions of the task highlighted the clustered version of the task produced a larger proportion of correct recall ($M = .685$; $SE = .020$), than the non-clustered version ($M = .528$; $SE = .014$), $F(1,11) = 65.098$, $p = .001$, $\eta p^2 = .857$. The significant serial position effects, $F(8,88) = 17.118$, $p = .001$, $\eta p^2 = .609$, and multiple pairwise comparisons showed that serial positions one to six (range: .450-.603) did not differ from each other. The rising recency effect was evident in the last three positions, systematically rising at each point (all $ps < .05$). The interaction between the two factors was non-significant, $F(8,88) = 1.744$, $p = .099$, $\eta p^2 = .137$, suggesting that the serial position effects produced was not affected by whether the stimuli was clustered together by their category or randomised (Figure 6.3).

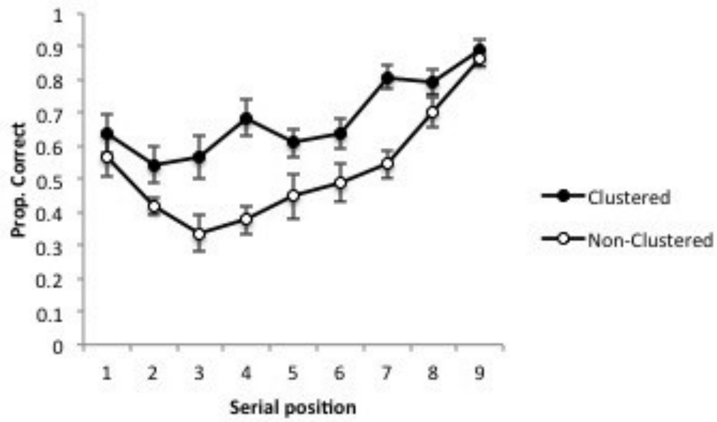

Figure 6.3: The proportion of correct recall as a function serial position and the two versions of the conceptual span task. Error bars represent one standard error from the mean.

To determine whether the alteration in the change of stimuli affected its relationship to WMC, correlational analyses was conducted using the adults clustered and non-clustered proportion of correct recall and their listening span performance as an index of WMC (Table 6.1). The results demonstrated that whilst the non-clustered version was significantly linked to WMC, the clustered version was not.

Table 6.1: The correlations between the clustered and non-clustered versions of the conceptual span task and WMC

Task Version	WMC	*p*-value
Clustered Conceptual Span Task	.040	.810
Non-Clustered Conceptual Span Task	.395	.013

6.3.3 Error analysis for the conceptual span task

According to Unsworth and Engle (2007b), low WMC individuals should recall fewer target items from the presented list, and emit more intrusions when compared to high WMC individuals. Errors were collected for adults and children and placed into two categories: association errors and prior list intrusions (PLIs), based on Unsworth (2009). A category association error was a word association effect whereby participants recalled alternative items that were associated with the category. There were also non-category errors, recalled items that were not associated with the cued category and were not part of the stimuli pool. The next type of errors were category or non-category PLIs whereby participants recalled items from previous lists instead of the current list. Finally, list intrusions were the recall of items from the current list, which were not associated with the cued category.

A 5 (error type: category error vs. noncategory error vs. category PLI vs. non-category PLI vs. list intrusion) x 3 (age: Year 3 vs. Year 5 vs. Adults) mixed factor ANOVA showed a significantly higher number of category errors, followed by category PLIs, $F(4,596) = 153.731$, $p = .001$, $\eta p^2 = .508$. All other errors were very low. A significant effect of age, $F(2,149) = 14.511$, $p = .001$, $\eta p^2 = .163$, and a posthoc test using a Bonferroni correction, once again showed no difference between the two children groups ($p = 1.000$), but both children groups produced significantly more errors than adults (both $ps = .001$). A significant interaction between the two factors $F(8,596) = 8.423$, $p = .001$, $\eta p^2 = .102$, highlighted that age-related differences in errors were evident in the category errors, $F(2,161) = 11.734$, $p < .001$, $\eta p^2 = .136$; category PLIs, $F(2,151) = 3.287$, $p = .040$, $\eta p^2 = .042$; and list intrusions, $F(2,151) = 6.355$, $p = .002$, $\eta p^2 = .079$ (Figure 6.4). The category errors showed both sets of children produced equivalently high levels of these types of errors in comparison to the adults. Category PLIs on the other hand showed Year 5 to produce significantly more of this type of error than both Year 3 and adults, whilst the only difference within the list intrusion error was Year 3 producing significantly more of this error than the adults.

Using the different types of errors, the next question examined which type of error was more likely to occur in the beginning middle or end of the task procedure. The conceptual

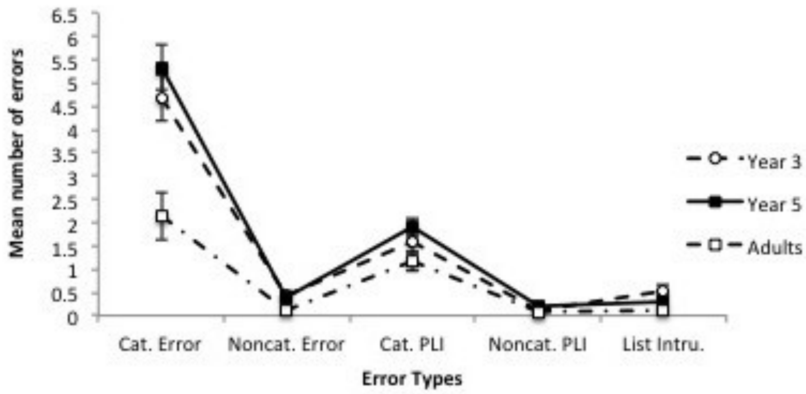

Figure 6.4: The mean number of errors produced as a function of error type and age. Error bars represent one standard error from the mean. Cat. Error = Category Error; Noncat. Error = Noncategory Error; Cat. PLI = Category Prior List Intrusion; Noncat. PLI = Noncategory Prior List Intrusion; List Intru. = List Intrusion

span task trials was split into three sections: trials one to four was labelled the beginning section; trials five to eight the middle section; and trials nine to 12 was the end section. A 5 (error type: category error vs. noncategory error vs. category PLI vs. noncategory PLI vs. list intrusions) x 3 (task section: beginning vs. middle vs. end) x 3 (age: Year 3 vs. Year 5 vs. Adults) mixed factor ANOVA showed a significant main effect of task section, $F(2,298) = 20.280$, $p = .001$, $\eta p^2 = .120$. Multiple pairwise comparisons with a Bonferroni correction showed the beginning section generated the fewest errors than both the middle and end sections (both *ps* = .001), of which did not differ from each other ($p = 1.000$). The interaction between task section and age was approaching significance, $F(4,298) = 2.367$, $p = .053$, $\eta p^2 = .031$. As previously acknowledged there were age-related differences across all sections (beginning section: $F(2,149) = 10.456$, $p < .001$, $\eta p^2 = .123$; middle section: $F(2,149) = 10.805$, $p < .001$, $\eta p^2 = .127$; end section: $F(2,149) = 11.382$, $p < .001$, $\eta p^2 = .133$). As demonstrated in Figure 6.5A, adults consistently produced fewer errors in all sections (all *ps* > .05). Year 3 produced significantly more errors than Year 5 in the beginning section ($p = .046$), this difference disappeared for the subsequent two sections (all *ps* > .05).

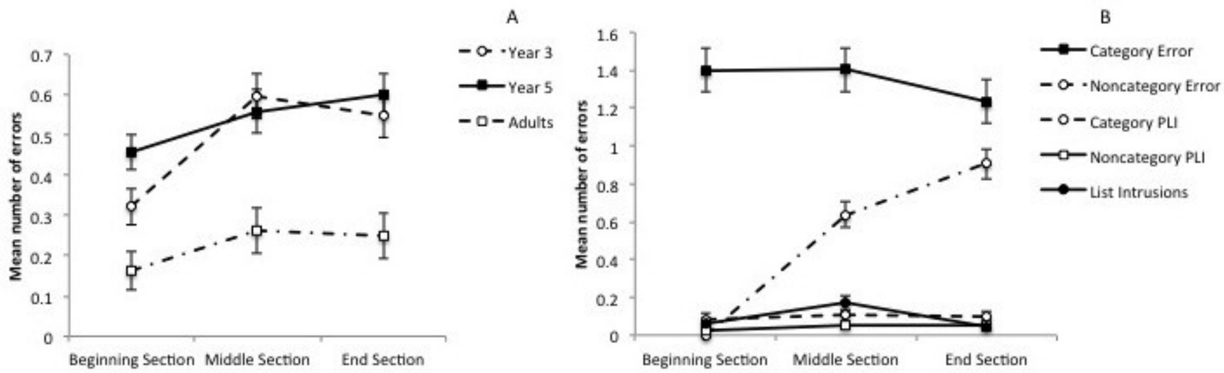

Figure 6.5: The mean number of errors as a function of task section and age (A); and task section and error type (B). Error bars one standard error from the mean.

The interaction between task section and error type, $F(8,1192) = 18.267$, $p = .001$, $\eta p^2 = .109$, suggested that the number of category PLIs and list intrusions made were affected as a function of task section (category PLI: $F(2,298) = 65.693$, $p < .001$, $\eta p^2 = .306$; list intrusion: $F(2,298) = 5.367$, $p = .005$, $\eta p^2 = .035$). The number of category PLIs systematically increased across the three sections (all *ps* < .05). The differences in list intrusions was attributed to a higher level of errors in the middle section in comparison to the beginning and end sections (all *ps* < .05). All other error types remained relatively equal across the three sections (category error: $F(2,298) = 1.330$, $p = .266$, $\eta p^2 = .009$; noncategory error: $F(2,298) = .119$, $p = .888$, $\eta p^2 = .001$; noncategory PLI: $F(2,298) = 1.062$, $p = .347$, $\eta p^2 = .007$). The three-way interaction between task section, error type and age was non-significant, $F(16,1192) = 1.545$, $p = .077$, $\eta p^2 = .020$, thus indicating that all age groups produced a similar pattern of errors.

6.3.4 Delayed cued recall task

Performance on this task was compared with the data collected from the previous experiment. This was to determine any consistencies in the age-related differences that were previously found, indicative of developmental differences in the retrieval of memory items from SM. A 2 (experiment version: Experiment 4 vs. Experiment 5) x 3 (serial position: position one vs. position two vs. position three) x 3 (age: Year 3 vs. Year 5 vs. Adults) mixed factor ANOVA revealed systematic age-related increases in recall accuracy (Year 3: M = .401; SE = .014; Year 5: M = .457; SE = .014; Adults: M = .723; SE = .016), $F(2,260) = 127.533$, $p < .001$, $\eta p^2 = .454$. Overall accuracy was lower in the current experiment (M = .483; SE = .011) in comparison to Experiment 4 (M = .570; SE = .013), $F(1,260) = 26.113$, $p < .001$, $\eta p^2 = .130$. However, the significant interaction between the two factors, $F(2,260) = 3.366$, $p = .036$, $\eta p^2 = .025$, showed this was the case for Years 3 and 5 (Year 3: $F(1,92) = 9.987$, $p = .002$, $\eta p^2 = .098$; Year 5: $F(1,92) = 27.386$, $p = .001$, $\eta p^2 = .229$). The adults did not show an effect of experiment version, $F(1,76) = .950$, $p = .333$, $\eta p^2 = .012$. Developmental differences across the age range also differed between the two experiments. Multiple pairwise comparisons using a Bonferroni correction revealed that performance on the delayed cued recall task in Experiment 4 showed systematic increases across the three age groups (all $ps < .05$). Years 3 and 5 did not differ in the current experiment ($p = .906$), but performed at a significantly lower level than the adults (both $ps < .001$).

The significant effect of serial position, $F(2,520) = 9.856$, $p = .001$, $\eta p^2 = .037$, was followed by significant interactions between serial position and age, $F(4,52) = 4.902$, $p = .001$, $\eta p^2 = .036$, serial position and experiment version, $F(2,520) = 15.624$, $p = .001$, $\eta p^2 = .057$ and a three-way interaction between all three factors, $F(4,520) = 2.921$, $p = .021$, $\eta p^2 = .022$. As demonstrated in Figure 6.6A and B, the accuracy across serial positions differed considerably as a function of experiment version and age group. Individual analyses of each serial position revealed Year 3 performed at equivalent levels across experiment versions at serial positions one, $F(1,93) = .001$, $p = .979$, $\eta p^2 = .000$ and two, $F(1,93) = 1.962$, $p = .165$, $\eta p^2 = .021$), but the recall of the final position was higher in Experiment 4, $F(1,93) = 21.019$, $p < .001$,

ηp^2 = .186. Only Year 5 were outperformed in Experiment 4 across all three serial positions (position one: $F(1,93) = 4.005$, $p = .048$, $\eta p^2 = .042$; two: $F(1,93) = 5.394$, $p = .022$, $\eta p^2 = .055$; three: $F(1,93) = 33.924$, $p < .001$, $\eta p^2 = .269$). Adults showed a higher recall accuracy for serial position one in Experiment 4, $F(1,78) = 5.776$, $p = .010$, $\eta p^2 = .071$, but a higher recall accuracy for position two in Experiment 5, $F(1,78) = 7.980$, $p = .006$, $\eta p^2 = .095$. For the final position there was no difference in accuracy between the two experiments, $F(1,78) = 2.663$, $p = .107$, $\eta p^2 = .034$.

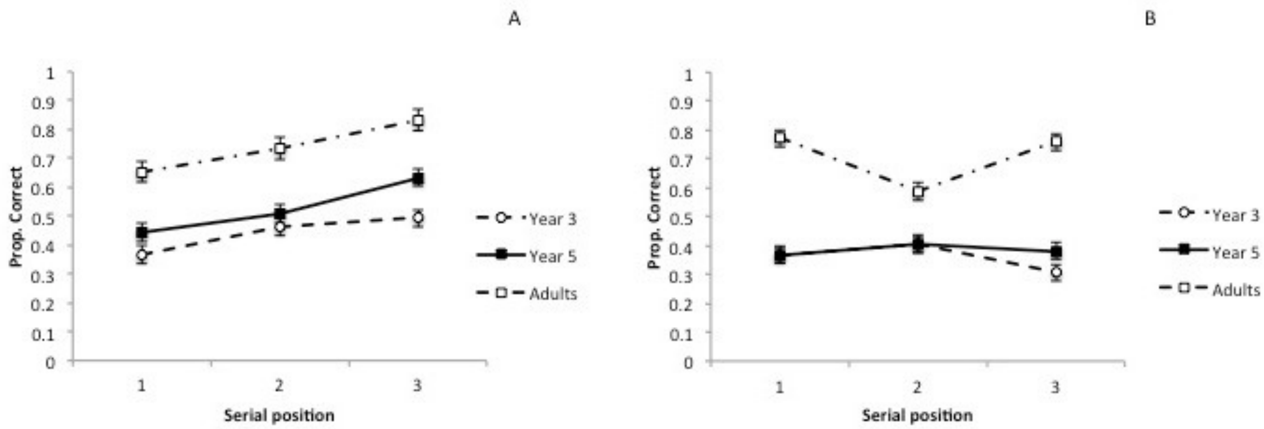

Figure 6.6: The comparison of the proportion of correct recall as a function of experiment version, serial position and age. A = Experiment 4; B= Experiment 5. Error bars represent one standard error from the mean.

The same type of ANOVA was performed on the dependent variable RT. The developmental decrease in RT was again evident (Year 3: $M = 3.678$s; $SE = .140$; Year 5: $M = 2.778$s; $SE = .137$; Adults: $M = 1.647$s; $SE = .145$), $F(2,265) = 42.152$, $p = .001$, $\eta p^2 = .245$, but participants responded quicker in the current experiment ($M = 2.441$s; $SE = .107$) than Experiment 4 ($M = 2.959$s; $SE = .122$), $F(1,265) = 6.283$, $p = .013$, $\eta p^2 = .024$. However, this effect was only evident in Year 3, $F(1,93) = 10.268$, $p = .002$, $\eta p^2 = .100$. Year 5 and adults showed no difference in RT as a function of experiment version (Year 5: $F(1,93) = .007$, $p = .935$, $\eta p^2 = .000$; Adults: $F(1,77) = 2.232$, $p = .139$, $\eta p^2 = .029$), reflected in the significant interaction between experiment version and age, $F(2,265) = 3.269$, $p = .040$, $\eta p^2 = .025$.

In addition, there was no effect of serial position, $F(2,468) = 1.293$, $p = .275$, $\eta p^2 = .005$. The significant interaction between serial position and experiment version, $F(2,468) = 3.983$, $p = .019$, $\eta p^2 = .017$, showed equivalent RTs for positions one and two across the two experiments (position two: $F(1,255) = 1.890$, $p = .170$, $\eta p^2 = .007$; position two: $F(1,260) = .469$, $p = .494$, $\eta p^2 = .022$). However, in the current experiment, participants were quicker at retrieving memory items at serial position three in comparison to Experiment 4, $F(1,256) = 14.595$, $p = .001$, $\eta p^2 = .054$. The interaction between serial position and age was non-significant, $F(4,468) = 1.615$, $p = .169$, $\eta p^2 = .014$, as was the three-way interaction between serial position, experiment and age, $F(4,468) = 2.025$, $p = .090$, $\eta p^2 = .017$.

6.3.5 Reading comprehension measures and their relation to WMC and SM

This section only involved children data as the adults did not complete any reading or vocabulary measures. Five children were excluded from the dataset as they were unable to complete the assessments (Year 3 $N = 49$; Year 5: $N = 51$). Illustrated in Figure 6.7, age-related increases for the BPVS vocabulary measure, $F(1,99) = 23.464$, $p = .001$, $\eta p^2 = .196$, the YARC reading accuracy measure, $F(1,99) = 19.811$, $p = .001$, $\eta p^2 = .170$, and YARC reading comprehension measure, $F(1,99) = 29.921$, $p = .001$, $\eta p^2 = .236$, were evident.

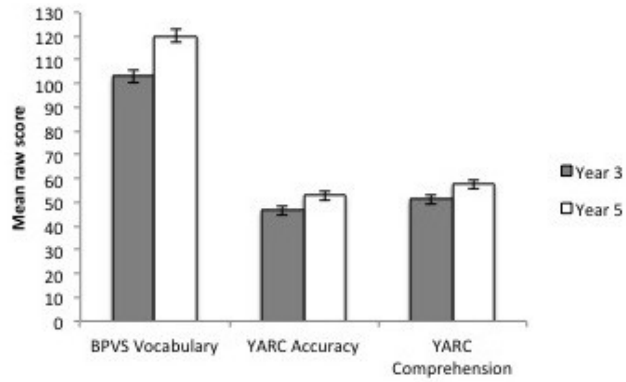

Figure 6.7: The age-related differences across the vocabulary and reading comprehension measures. Error bars represent one standard error from the mean.

A series of zero-order and partial correlations were run using children's experimental measures of delayed cued recall, conceptual span and WMC plus measures of reading comprehension and vocabulary. The zero-order correlations are presented in Table 6.2. A lot of the measures correlated with each other. The delayed cued recall and conceptual tasks significantly correlated with each other, indicating cognitive commonalities as methods to measure SM. In addition, both memory measures significantly correlated with WMC, reading comprehension and vocabulary. WMC also correlated with reading comprehension and vocabulary.

Table 6.2: The correlational analysis between all experimental measures.

	1.	2.	3.	4.	5.	6.	7.	8.	9.
1. Delayed RT	-	-.208*	-.052	-.196	-.139	-.155	-.133	-.119	-.090
2. Delayed Acc		-	.360***	.304**	-.047	.192	.288**	.325***	.118
3. Conceptual			-	.327***	-.111	.292**	.447***	.448***	.174
4. WMC				-	.061	.380***	.473***	.476***	.366***
5. Category PLI					-	.092	.202*	.226*	.120
6. YARC Acc						-	.561***	.596***	.400***
7. YARC Comp.							-	.743***	.471***
8. Vocabulary								-	.436***
9. Age									-

Note. Delayed RT = Delayed Cued Recall Response Time; Delayed Acc.= Delayed Cued Recall Accuracy; Conceptual = Conceptual Span Task; WMC = Working Memory Capacity; PLI = Prior List Intrusions; YARC Acc. = York Assessment of Reading Comprehension Accuracy; YARC Comp. = York Assessment of Reading Comprehension.

$p < .05$* $p < .01$** $p < .001$***

Partial correlations were carried out controlling for age and vocabulary (Table 6.3). Controlling for age, the delayed cued recall accuracy and the conceptual span measures still positively correlated with WMC and reading comprehension. As did WMC and reading comprehension. Controlling for vocabulary, substantially reduced the correlations. The delayed cued recall accuracy and conceptual span task inter-relation remained, indicating, a cognitive commonality in the ability to retrieve information from SM through external cues. Reading comprehension significantly correlated with WMC and reading accuracy, whilst the conceptual span task was nearing significance (p = .065).

Table 6.3: The partial correlations between age, vocabulary, reading comprehension measures and memory measures. The upper triangle reports the partial correlations controlling for age; the lower triangle reports the partial correlations controlling for vocabulary.

	1.	2.	3.	4.	5.	6.	7.
1. Delayed RT	-	-.200*	-.037	-.175	-.130	-.131	-.103
2. Delayed Acc	-.181	-	.347***	.282**	-.062	.159	.265**
3. Conceptual	.001	.253*	-	.287**	-.135	.249*	.420***
4. WMC	-.159	.179	.145	-	.081	.274**	.366***
5. Category PLI	-.116	-.131	-.244*	-.055	-	.048	.166
6. YARC Acc.	-.106	-.002	.037	.137	-.054	-	.461***
7. YARC Comp.	-.068	.074	.190	.202*	.053	.220*	-

Note. Delayed RT = Delayed Cued Recall Response Time; Delayed Acc.= Delayed Cued Recall Accuracy; Conceptual = Conceptual Span Task; WMC = Working Memory Capacity; PLI = Prior List Intrusions; YARC Acc. = York Assessment of Reading Comprehension Accuracy; YARC Comp. = York Assessment of Reading Comprehension.

p < .05* p < .01** p < .001***

A set of hierarchical regressions examined the extent to which the working memory measures (listening span, conceptual span and the accuracy measure of delayed cued recall tasks) and vocabulary contributed to reading comprehension. Age was entered on the first step of each regression to control for any general age-related effects. Following this, the working memory measures or vocabulary were entered as either the second or third steps. The final step was included to examine the extent to which either working memory or vocabulary would account for unique variance of reading comprehension, over and beyond the previously entered measures (see Table 6.4).

Table 6.4: Hierarchical regressions predicting variation in reading comprehension. Top table: working memory = delayed cued recall, conceptual span and listening span; bottom table: working memory = conceptual span and listening span.

Step	IV	ΔR^2	*F*	*df*	*p*
1	Age	.222	26.863	1,94	.001
2	Working memory	.193	10.004	3,91	.001
3	Vocabulary	.188	42.760	1.90	.001
1	Age	.222	26.863	1,94	.001
2	Vocabulary	.357	78.711	1,93	.001
3	Working memory	.025	1.873	3,90	.140

Step	IV	ΔR^2	*F*	*df*	*p*
1	Age	.222	26.863	1,94	.001
2	Working memory	.188	14.692	2,92	.001
3	Vocabulary	.193	44.274	1,91	.001
1	Age	.222	26.863	1,94	.001
2	Vocabulary	.357	78.711	1,93	.001
3	Working memory	.025	2.833	2,91	.064

The first regression analyses included all three measures of working memory. This produced a model that accounted for 60.4% of the variance, $R^2 = .604$, $F(5,90) = 27.400$, $p < .001$. Vocabulary significantly accounted for 18.8% of the variance, above and beyond all other measures. The working memory measures contributed to 2.5% of the variance, which was not significant. Further detailed analysis revealed that delayed cued recall task did not contribute to the ΔR^2, and was therefore removed from the analysis.

A second regression analyses was carried out, removing the delayed recall recall task from the model. Overall, all independent variables accounted for 60.3% of the total variance when predicting reading comprehension, $R^2 = .603$, $F(4,91) = 34.621$, $p < .001$. Vocabulary explained a significant amount of unique variance when entered on the third step of the regression, $\Delta R^2 = .193$, $F(1,91) = 44.274$, $p < .001$. This is in contrast to the working memory measures at the third step, that exerted a marginal, albeit modest, significant amount of unique variance, $\Delta R^2 = .025$, $F(2,91) = 2.833$, $p = .064$.

6.4 Discussion

The final aim of the thesis was to investigate whether a retrieval-based perspective of working memory could help explain the relationship between working memory and reading comprehension away from working memory models that focus on the active maintenance of items (Baddeley & Hitch, 1974; Daneman & Carpenter, 1980; Just & Carpenter, 1992). In order to explore this thoroughly, a task taken from the adult literature was adopted, the conceptual span task, previously found to contribute to complex cognition, and specifically reading comprehension (Haarmann et al., 2003). Alongside the delayed cued recall task, adults' and children's ability to retrieve memory items from a longer-term store was compared. To provide a more thorough understanding of the tasks themselves and reading comprehension, a measure of vocabulary was also collected to ascertain mediating factors within the relationship between working memory and reading comprehension.

The conceptual span task was a cued free recall task, a conceptual extension of the delayed cued recall task. Specific analysis of the pre-recency section from the conceptual span task was of particular interest. Previous attempts within this thesis have been made to try and enhance the recall of this section; the use of extended presentation rates and presentation modality in free recall tasks (Experiments 1 and 3), and the use of recall probes in the probed split span task (Experiment 3). Interestingly, the conceptual span task showed elevated levels of recall when compared to the auditory free recall data from Experiment 2 across all age groups. Whilst the two tasks did not differ in recall performance within the primacy section, the recall of items from the middle section of the conceptual span task was enhanced. Therefore, children appeared to show the ability to store memory representations outside of PM, and carry out controlled retrieval processes from SM in a free recall context.

The recency section was also boosted in the conceptual span task, which was not considered as a potential finding, but plausible. SM is thought to be responsible for semantic and associative features of words, whilst items in PM are encoded in an acoustic, articulatory fashion (Adams, 1967; Neisser, 1967). However, it may be that any salient feature, in this case semantics, could elevate the recall of recency items as it provides an additional component that makes an item even more accessible in its conscious, transient state.

As part of examining the design of the conceptual span task, the adults completed the clustered and non-clustered versions of the task. The former task produced a higher proportion of correct recall, but both tasks produced similar serial position effects. The results from the current comparison of the two versions of the task revealed that whilst the non-clustered conceptual span positively correlated with WMC, this was not the case for the clustered conceptual span task. Kane and Miyake (2007) also used a clustered conceptual span task to assess its predictive power in regards to complex cognition, to find it did not predict any additional variance in language ability (i.e. reading comprehension) or fluid intelligence above and beyond short-term memory tasks. This is in contrast to Haarmann et al. (2003) who found both versions of the conceptual span task correlated with reading comprehension above and beyond complex span tasks. However, the correlation was weaker for the clustered version of the task. Haarmann et al. claimed that the task indexes how well and how quickly participants are able to mentally organise list items into their semantic categories. It is possible that the recall of three clustered items was too easy for the adults, and did not require the processes provided by working memory.

Differences in the findings could be attributed to the size of the clusters used. Kane and Miyake (2007) used three- to five-item clusters and found no prediction of higher-order cognitive abilities above and beyond short-term memory tasks. Interestingly, Saito (2006) used the same sized clusters as Haarmann et al. (2003) in semantic and coloured tasks, and reported the clustered tasks were poor predictors of sentence comprehension measures in comparison to non-clustered conceptual tasks. The adults in the current experiment did not take part in a reading comprehension measure, and so it is not possible to contribute to understanding any links between the clustered conceptual span task and reading comprehension. However, based on the evidence accrued, the ability to mentally organise list items into their semantic categories needs to be considered contributing to the relation with working memory and complex cognition regardless of the number of items used in the task.

To broaden our understanding of SM, errors from the conceptual span task were investigated. All age groups recalled increasingly more PLIs throughout the task, indicative of proactive interference building up over successive trials (Unsworth, 2007, 2009; Unsworth & Engle, 2006a, 2007b). Contextual elements of target items may share contextual elements with items from previous trials. Therefore, the probability of PLIs being included in the search set are increased. Unsworth (2009) suggested that adults with low-WMC use a larger search set, meaning retrieval is less focused, thus resulting in lower recall and more intrusions. This is also a plausible explanation for the children's data. They are storing the items in SM, but are unable to use appropriate contextual cues to retrieve the target memory items. This has to be overcome at the time of retrieval, a process that also requires attention (Healey & Miyake, 2009). An additional issue is the type of cues that children decide to use. Key to successful retrieval from SM is the ability to use a variety of contextual cues. In episodic memory tasks, such as free recall, temporal-contextual cues are particularly important as they enable participants to distinguish which memory representations are from the current list and which are from previous lists. It is possible that children are relying on the external semantic cues provided, which becomes the emphasis of children's retrieval strategy, as opposed to also applying their own internal temporal-contextual cues. Therefore, they are not controlling which items were from previous lists and need to be ignored, and which items are from the current list and need to be retrieved.

Interestingly Year 5 produced more PLIs than both Year 3 and adults. There are two potential explanations for this. Firstly, younger children use a smaller search set and therefore they do not hold as many items, including intrusions, naturally reducing not only the number of items retrieved, but also the number of intrusions produced. An additional potential explanation is the question of recoverability of memory representations. Based on our understanding of when children begin to use maintenance strategies and rehearsal is it possible that the older nine- to tenyear olds are producing stronger target representations making memory representations more accessible at retrieval. However, their ability to focus the search and retrieval processes are still developing. Therefore, they have to manage more accessible memory representations, in an assumed larger search set, but are unable to internally generate more specific, appropriate cues to ensure only target memory representations are recalled.

The category association error was the most common error made, whereby children recalled items that were part of the target category, but not included within the list. Year 3 were particularly susceptible to this, recalling items such as apple and banana for the fruit category and football for the sports activities for example. Such items were excluded from the stimuli selection due to their high prevalence in the pilot data (see section 5.2.2). This helps confirm the rationale of the stimuli choice. If closely associated words had been used in the

SM tasks it is possible that children would have produced a higher proportion of recall, but at the expense of using other processes such as word association as opposed to SM retrieval processes.

Experiment 5 included the delayed cued recall task with the aim of replicating the previous findings from Experiment 4, but to also ascertain whether the delayed cued recall and the conceptual span tasks were tapping into the same cognitive mechanisms that underlie SM. As a sole measure of SM, adults' accuracy did not change as a function of experiment. This was not the case with the children. Both Years 3 and 5 recalled fewer items in comparison to the previous experiment, thus suggesting the current sample of children found the task even harder that those involved in Experiment 4. The measure of RT demonstrated that Year 3 responded quicker in the current employment of the task, whilst the adults and Year 5 responded at a similar rate to the previous experiment. Nonetheless, the results converged that children up to the age of ten-years, still have the task of developing efficient search and retrieval processes from SM in order to reach the level of adults. This time when age was controlled for in the correlational analysis, the negative correlation between accuracy and RT on the delayed cued recall task was significant, which had not been the case in the previous experiment. Therefore, children aged seven- to ten-years old, and adults, indicated those that were able to retrieve more items were also quicker at retrieving memory representations from SM, demonstrating individual differences in the efficient use of the SM system.

The conceptual span and the delayed cued recall tasks were adopted as potential measures of children's ability to retrieve target information from SM. In Experiment 4, the measures of delayed cued recall demonstrated significant correlations with WMC. In the current experiment, both measures correlated with each other even when age and vocabulary were controlled for, suggesting cognitive commonalities of strategic search and retrieval processes from a longer-term store away from any verbal abilities. The two SM measures also correlated with WMC, but this was lost when vocabulary was partialled out, indicating that vocabulary knowledge did influence the relationship between the SM tasks and WMC.

All measures of reading accuracy, comprehension and vocabulary showed age-related increases within the children's dataset. Vocabulary is already established as a key contributor to reading comprehension (Cain et al., 2004; Florit et al., 2009; Muter et al., 2004). General age-related effects did not impact the inter-correlations between the delayed cued recall task, conceptual span task, WMC, vocabulary and reading comprehension. However, when vocabulary was controlled for, the delayed cued recall task lost its significance with the reading comprehension task, thus suggesting this relation was mediated by vocabulary knowledge. However, the correlation between WMC and reading comprehension still remained, and the conceptual span task approached significance (p = .065).

The regression analyses showed that vocabulary provided a significant unique contribution even when age, and the working memory measures were controlled for. This was not the case for working memory. The inclusion of the delayed cued recall, conceptual span and listening span tasks showed a non-significant contribution to reading comprehension. When delayed cued recall was removed, the ΔR^2, did not change, but the F-ratio was approaching significance, thus suggesting the the delayed cued recall task was not contributing any variance to the model. As it stands, the data points to vocabulary being a key measure in children's reading comprehension. It is hard to conclude how retrieval abilities are linked to the established relationship between working memory and reading comprehension. The results suggest that SM is not involved in the access and retrieval of word meanings to help facilitate reading comprehension. This is possibly due to the immaturity of the SM processes of the children. Therefore, as a next step of enquiry, the measures of SM, WMC, reading comprehension and vocabulary needs to be carried out in adults to decipher the contributions of the same measures to reading comprehension. This will provide a better idea of whether retrieval based abilities within working memory contribute to reading comprehension, and the extent to which vocabulary knowledge is also involved.

Despite the categorisation and investigation of different types of errors to help understand the developing processes underlying SM as a key contributor to WMC, category PLIs did not correlate with WMC in children. Therefore, it is not possible to conclude that children with a developing WMC are likely to show greater PLIs as a consequence of an inefficient ability to focus search sets within SM. The zero-order correlations showed category PLIs positively correlated with vocabulary and reading comprehension. However, these were lost once age and vocabulary were partialled out. Therefore, not only are their general age-related differences affecting the relationship, it also suggests that vocabulary is influencing the relationship between PLIs and reading comprehension. It is possible that the long-term vocabulary knowledge of the semantic category provides additional salience to the memory representation, which is driving it's retrieval, despite it not being the correct item.

In line with Chapter 5, the displacement of memory items from PM to SM, reduces their accessibility substantially for children. The conceptual span task showed cognitive similarities with the delayed cued recall task, suggesting they were both tapping into participant's ability to retrieve SM representations from a longer-term store. It further demonstrated how difficult it was for children to carry out the demanding search and retrieval process, even for the oldest group of children. This has provided a developmental perspective of how SM processes emerge as part of WMC, and an explanation as to why children are so reliant on the active maintenance of memory items in PM. The notion of contextual cue-depedent retrieval processes within working memory was investigated as a means to understand the established relationship between working memory and reading comprehension. Vocabulary was the overriding predictor of reading comprehension. However, this could be a consequence of childrens slow, demanding retrieval processes. Therefore, children are more reliant on automatic access to long-term vocabulary knowledge to be successful at this type of complex cognition.

Chapter 7

General discussion

The five empirical experiments in this thesis investigated a suite of processes and signatures of specific memory systems among adults and children. The theoretical entry point for the work was the connection between PM and SM on the one hand, and WMC on the other. This was influenced by the renaissance of PM and SM as cognitive constructs that underpin working memory capacity (Unsworth & Engle, 2006a,b, 2007a,b). On the basis of individual differences in adult data, they propose that PM and SM provide independent contributions to working memory capacity. The concepts of PM and SM are founded on vague and potentially misleading methods, and derived from potentially over simplistic theories. The thesis has attempted to develop and evaluate both current and alternative ways of estimating different aspects of the memory system and process, and so to allow a more rigorous assessment of the concepts under investigation.

7.1 Experiments 1 and 2: Does PM and SM increase through childhood?

Experiment 1 took an exploratory approach to examine how children perform on free recall paradigms that are used to derive PM and SM estimates. In addition, the potential convergent measures of PM (SIIT) plus the experimental manipulations of presentation modality were examined to investigate differences in adults' and children's retention of memory representations in working memory.

The early (Atkinson & Shiffrin, 1968; Waugh & Norman, 1965) and more recent (Gibson et al., 2011; Unsworth et al., 2010; Unsworth & Engle, 2007b) models used free recall as a principal measure to investigate the different mechanisms incorporated into the dual-store and dual-memory frameworks respectively. The primacy effect is believed to reflect the ability to carry out controlled search and retrieval processes to access memory representations from a LTS or SM. The recency effect is an index of the active maintenance and recall of immediate information under the allocation of attention in a STS or PM. What separates the current work from the historical literature is the movement away from where items are stored, i.e. short-term or long-term store. It provided two sources of variance that focus on two different underlying processes necessary for children to access memory representations: immediate, highly accessible memory representations supported by PM and less accessible and harder to recover memoranda that requires more effortful strategic search processes, facilitated by SM.

Developmental increases in PM and SM use were evident in both the serial position effects and categorisation methods (Tulving & Colotla, 1970), which represents a challenge to claims in the literature that PM is age invariant (Cole et al., 1971; De Alwis et al., 2009; Thurm & Glanzer, 1971). The key difference between adults' and children's serial position curves was the evidence for primacy effects. Whilst adults showed more flexibility in where they began their recall, children were mainly restricted to the recency section of the list. Subsequently, adults produced both primacy and recency effects, whilst children of all ages presented dominant recency effects, but very little primacy. Therefore, based on the argument that the recall of primacy and recency effects are based on two different mechanisms, children are deficient in their ability to carry out controlled search and retrieval processes, but were able to actively maintain a limited number of memory items. Children's default recency strategy of unloading items from immediate memory, may be due to the type of attentional control necessary for the two different mechanisms. The attentional control required to actively maintain items in the face of distraction is manageable as there should not be anything to distract them internally or externally. In contrast, an attention-mediated ability to carry out contextual cue dependent search processes to retrieve target information is far more demanding. Not only do children have to generate their own internal, contextual cues that are sufficient enough to de-limit the search set, they also need the attentional resources to carry out the search process itself in order to retrieve memory representations.

The conceptual understanding of two different mechanisms driving primacy and recency effects is a consequence of the U-shaped serial position curve described by the original dual-store models (eg. Atkinson & Shiffrin, 1968). This research entailed using aggregate scores for each serial position, producing the well-established curve. However, just looking at the PFR of each age group confirmed the suggestion that it is too simplistic. Following the work of Gibson et al. (2011) and Unsworth et al. (2011), three recall initiation subgroups were identified within the three age groups: beginning recall with primacy items, beginning recall with recency items and the combination of the two strategies. Whilst the recency sub-group was a lot larger than the primacy and combination group, there was a percentage increase in the latter two subgroups as children got older. This investigation provided support for individual differences within age groups in how participants carried out free recall tasks. This affects the serial positions recalled, and in turn the serial position curves generated. Therefore, one cannot assume that adults and children all carry out free recall tasks in a similar fashion, applying specific mechanisms to specific sections of a list. It is necessary to investigate participants order of report to fully understand how they use the processes that underlie the two cognitive constructs.

The work by Tulving and Colotla (1970) provided a method that generates estimates of items recalled from PM and SM, but also which items were recalled from PM or SM (Watkins, 1974). Despite still being prevalent in recent adult literature (e.g. Mogle et al., 2008; Shelton et al., 2010; Shipstead et al., 2014; Unsworth et al., 2010), this method has not been explicitly used in children. Previous literature has either focused on serial position effects (Cole et al., 1971; Thurm & Glanzer, 1971; Jarrold et al., 2015) or other means to differentiate PM and SM recall (De Alwis et al., 2009; Jarrold et al., 2015). Consistent with the serial position analyses, children's use of SM was not affected in the same way as adults. However, before suggesting that this is direct evidence of the developing capacities of PM and SM, one has to be cautious about the validity of the method used. Children have a smaller memory capacity than adults, therefore, is it appropriate to instill adult capacities when classifying their recall performance? By doing so, results may be affected by over-estimations of one system at the expense of another. The current work used different thresholds to examine how it affected estimates of PM and SM. Future work now needs to take the next step as suggested by Jarrold et al. (2015) who suggested a different threshold should be adopted for each age group that was in alignment with their PM capacity.

Referring back to individual differences in recall performance, this provides another reason to be cautious. Tulving and Colotla's method rides on the assumption that all participants begin their recall with the recency section of a list. The data from Experiment 1 showed that this was not the case throughout the age ranges used. It is possible that some individuals focused their attention on actively maintaining the beginning items, and thus recalled them first. However, the method by Tulving and Colotla (1970) does not allow for this and would calculate an ITRI of over seven, classifying the item as retrieved from SM. Therefore, one cannot guarantee the validity of the estimates provided. It means that the use of the method should be restricted to trials in which participants begin recall with the final item of a list. This suggestion itself proves the method to not be robust enough to accommodate individual differences in free recall profiles.

The regression analyses suggested that in predicting WMC (as estimated from a listening span task), SM provided a larger unique variance than PM in children, but it was the opposite in adults. This was not expected, as it is suggested that SM is the driving force behind complex span performance (Unsworth & Engle, 2006b, 2007b; Unsworth, 2010). In addition, the children produced a larger shared variance between PM and SM, which was not the case in adults. Within five- to eight-year olds, it is possible that the two separate constructs are still reliant on a shared attentional resource that underlies the shared variance. By adulthood this is substantially reduced and the two cognitive systems are running independently of each other, fitting with the findings of Unsworth et al. (2010). This is suggestive of a transitional period later in childhood in which the systems are treated as independent processes within working memory. However, there is also the point to make that actually the descriptions provided by Unsworth and colleagues are too rigid. It is possible that that items displaced from PM are recycled back into PM as part of retrieval from SM (Unsworth, 2007). This needs to be further addressed to ascertain whether the findings present here are due to qualitative shifts in how PM and SM is used within WMC, or a structural simplicity that has caused a misinterpretation of the findings.

The free recall data and the risks surrounding its interpretation emphasised the necessity to develop new tasks that measure the cognitive profile of PM and SM as described by the dual-memory framework (Unsworth & Engle, 2007b). The SIIT task in Experiment

1 investigated the cognitive profile of PM in more detail. Therefore, it not only provided supportive evidence of increasing PM capacity, but also how this cognitive construct managed information of different modalities and the necessary implementation of attentional strategies to successfully recall target information in the face of distraction. Age-related increases in the number of items held in working memory supported the PM capacity increase. In addition, the age-related increase in the proportion of focal recall demonstrated children's ability to select which items need to be actively maintained in the face of distraction. This supported the developing ability to allocate attention effectively. The developmental decrease in nonfocal recall between Years 1 and 3 was further evidence of developing abilities in the use of selective attention to maintain target information despite distractions in the environment. However, adults produced equivalent levels of nonfocal recall as Year 1. Due to the size of the list lengths it is possible that adults were able to attend to the two information steams. Then at recall, depending on the recall instruction provided they were able to select the recall of focal or nonfocal items.

As part of Experiment 1, the PM estimates gathered from the free recall data and the number of items held in working memory were compared to determine age-related increases in PM capacity. Age-related increases were evident in both measures of PM capacity, but at differing levels of recall. This was similar to Hall et al. (2015) who found different PM capacities across three different tasks, all of which were believed to show signatures of PM. Unsworth (2007) argued that PM is a dynamic, flexible system that adapts to the task demands. Related work by Cowan (2005) proposed the role of an adjustable attentional focus, which is a more general, flexible attentional system and suggested Attention can zoom in to hold onto a goal despite the presence of interference but it can also zoom out to apprehend up to about four separate chunks of information at once in the absence of interference (p. 482). The current findings in this thesis fit with Unsworth and Engle's more dynamic description of PM, and the concept of attentional flexibility dependent on the goals of the task. Thus, task situations, such as the SIIT, it is optimal for PM to be restricted when in the presence of distracting or interfering information. However, in tasks such as free recall it is important to keep the size of PM at its maximum to maintain as many distinct memory representations as possible. Taking into consideration all the points of discussion in regards to the active maintenance of a fixed number of memory representations in PM, the findings point towards the notion of children's developing control to allocate attention to target information, contributing to individual differences in PM capacity.

Presentation modality was implemented into the design of the SIIT to determine whether PM showed any elements of domain-specificity in regards to the storage of immediate information. Children's ability to be selective, encode, manage and retain focal information was affected by whether the information was auditory, visual or a combination of the two. Vocal labelling of the visual pictures was used to explain why the visual condition produced the highest level of focal recall and the lowest level of nonfocal recall. In contrast, auditory information seemed to have obligatory access to the cognitive system, cluttering children's working memory with irrelevant information. This also seemed to happen to adults who were not able to overcome the high accessibility of auditory nonfocal information. Interestingly, the dual condition generated the highest level of nonfocal recall, suggesting that the visual memory representation was strengthened by the combined auditory component, making it harder for participants to not allow it to appear at recall.

The modality differences described provided indications of domain-specificity. However, this could not be supported until an alternative explanation was eliminated. It was suggested that as a consequence of the experimental layout of stimuli, the visual condition of the SIIT task was more of a measure of short-term memory, whilst the auditory condition reflected selective attentional abilities and its contribution to the active maintenance of items in immediate memory. This was based on the fact that when the pictures were shown, participants had the opportunity to focus on one side of the screen, retaining the focal items, but ignoring the nonfocal items. This was not possible in the auditory and dual conditions as the stimuli were presented through headphones, making them much harder to ignore.

Experiment 2 investigated whether the presentation configuration might have affected recall strategies. Data supported this interpretation, because there was no modality effects in the recall of focal and nonfocal recall when all the stimuli appeared in the centre of the screen. Participants no longer had the option to be as selective with which visual items were labelled or not. By making this subtle change it equalised the levels of attentional distribution across the two modalities, and provided a less confounded suggestion that PM acts as a domain-general system. Therefore, auditory and visual information are managed by a domain-general resource, located in a store that is susceptible to disruption through the processing, encoding and recall of irrelevant information. However, the modality-specific versions of the SIIT did highlight that auditory information does have a greater accessibility when the two sources of information experienced are not in competition with each other and provide an obvious selectiveness at presentation. Therefore, in such situations it must be acknowledged that the data presents itself with elements of domain-specificity.

The change in experimental layout also affected the attentional mechanisms necessary to allocate attention effectively, changing the direction of developmental differences in nonfocal recall. Developmental increases in nonfocal recall were evident between Years 1 and 3. This suggested that it was much harder for younger children to differentiate the priority of the two different streams of information. Whilst rapidly shifting their attention from one source to another, they also had to demonstrate the control to to select target information. Therefore, the development of this type of attentional control will contribute to children's ability to actively maintain memory items in an immediate memory system. This will also exaggerate modality differences. It is much harder to quickly switch between two sources of information and translate a visual picture into a verbal code quickly, in comparison to retaining information already in a verbal form.

The continuation of such work will influence our understanding of children's ability to control the flow of information entering working memory, but also their ability to retain and recall target information. The free recall tasks and all versions of the SIIT support the notion that PM capacity develops throughout children supportive of the work by Hall et al. (2015) and Jarrold et al. (2015). However, the use of free recall to ascertain developmental differences in PM and SM need to use more flexible criterion to generate more reliable and valid estimates that accommodate the age-related and individual differences evident in participants' performance.

7.2 Experiment 3: Are children able to access items from a longer-term store?

The probed split span task investigated the accessibility of memory representations that are out of the immediate consciousness, and therefore need to be retrieved from SM. This followed on from the free recall findings in Experiment 1, whereby children kept to a recency recall strategy, demonstrating an inability to recall primacy items. In addition to this, it was questioned whether presentation modality contributed to the accessibility of memory items. Firstly, free recall tasks isolating auditory and visual information showed that visual primacy items were more likely to be recalled than auditory primacy items. This was the first indication that visual memory representations are more accessible when they are no longer in the focus of attention due to the combination of visual and verbal memory representations generating stronger memory representations than just auditory representations alone.

The probed split span task incorporated recall probes to question whether the lack of a primacy effect was due to an inability to recall primacy items or a reluctance to recall such items. Therefore, within a free recall context recall probes were included, i.e. participants instructed to begin recall with primacy items (first segment recall probe), recency items (second segment recall probe) or to use their natural recall strategy (full list recall probe). As an additional component, the two presentation modalities were used to partition lists into their respective segments. The use of recall probes highlighted that children were not able to generate an elevated level of recall for items at the beginning of the list even when instructed to. Children still kept to their rigid recency output strategy. Adults were able to adhere to the aims of instructing the recall of items at the beginning of the list, but only when they comprised of auditory items. This indicates that regardless of what you instruct participants to do, the recall strategy they are confident with is crucial to the process. It was evident that the adults were not always able to begin their recall with primacy items, and therefore it is not entirely surprising that children were not able to either.

There were additional suggestions that the representations of memory representations may impact their accessibility. The presentation modality of beginning list items had no impact on children's ability to recall them. However, there were indications that auditory items at the end of the list were far more accessible, fitting with the SIIT k value findings from Experiments 1 and 2. Despite this, participants were unable to recall the auditory items to the same extent when they had to be recalled second. In contrast, the visual memory representations seemed to generate more consistent, robust memory representations. This was indicated by the inverted modality effect being present when participants had to recall visual primacy items after the recall of auditory recency items, which was found in children as young as five years of age. Therefore, the way in which information is held within working memory does affect individual's recall characteristics. This is not considered within the dual-memory framework, but is a future avenue of investigation in determining how different types of information are maintained, managed and recalled from the two independent constructs of PM and SM.

7.3 Experiments 4 and 5: Developing efficiency in the ability to access and retrieve memory representations

Experiment 4 adopted tasks from the adult literature that were adapted to address the characterisation of SM in children. The cued listening span was implemented. As suggested by the name, this was a complex span task with the addition of cues to prompt the recall of items believed to be forgotten. In addition to assessing recall in a conventional, unprompted context, children and adults were provided with two different types of recall cues. These cues focused on the to be remembered word, and the sentence from which the to be remembered word was situated in. This experiment follows the themes of earlier studies that have suggested that adults and children use contextual information to reconstruct target memory representations that are no longer being maintained in an active state (Cowan et al., 2003; Towse et al., 2008b, 2010). Also, this experiment contributes to the question of the relationships between processing and storage because, a cooperative relationship between the two elements provides contextual support, enhancing recall. This is in contrast to arguments that describe a competitive relationship between the two elements due to the limited resources available (e.g. Case et al., 1982; Daneman & Carpenter, 1980; Towse et al., 1998).

The cued listening span task questioned whether the information stored was actually accessible, but children's deficiency was due to the retrieval process itself. The sentence cue was more effective in the recovery of SM items than the word cues. By providing the context in which the target word was initially presented triggered the reconstruction of memory representation. In comparison, when provided with new information that was not part of the initial encoding, but was associated with the forgotten memory item is a far more demanding process and provides fewer attributes that an individual can use to reconstruct the target item. Therefore, it is possible for children as young as five-years old to access information believed to be forgotten when provided with contextual support.

To follow the idea of providing external cues to help facilitate SM retrieval, the delayed cued recall task was adopted based on the work by Miyake and Friedman (2004). In between the presentation of memory items and the cued response, participants had to complete a distractor activity, forcing children to displace memory items into a longer-term store in order to assess their ability to carry out controlled retrieval from SM. This task supported the belief that items displaced from SM were still accessible, but demonstrated the extent to which children found it difficult to retrieve information from a longer-term store. The proportion of correct recall in the delayed cued recall task ranged from 35.4% - 52.8% in children aged five- to ten-years. The demands of retrieval were further demonstrated by the youngest age group taking up to 7.86s to retrieve one target item. With the findings of this experiment taken into account, it provides a perspective as to why children found it so hard to recall primacy items. Nonetheless, both measures significantly correlated with WMC. Those individuals with a higher WMC demonstrated an increased efficiency in SM; producing quicker, more accurate responses.

The conceptual span task was introduced in Experiment 5 as an additional measure of SM retrieval, following experimental similarities with the delayed cued recall task. However, instead of having to retrieve one item, this was extended to three items. Unlike the free recall paradigms and probed split span tasks from Experiments 1 and 3, the use of semantic cues did provide enhanced recall of pre-recency items, indicating a deficiency in the generation of internal cues necessary to initiate the retrieval process. This task complimented the portrayal of SM in children by analysing the types of errors made. Of particular interest, was the systematic increase of PLIs across task trials, indicative of a build-up of proactive interference.

This was a further indication that children were able to store memoranda in SM, attributing under-developed cue-dependent search and retrieval process as the potential issue underlying why children find it so difficult to use SM.

As part of its investigation, Experiment 5 gathered measures of reading comprehension to evaluate whether retrieval processes contributed to the relationship between working memory and reading comprehension. The inter-relations were evident between the memory measures and reading comprehension. However, vocabulary seemed to have a greater influence on performance, substantially reducing the majority of the correlations between the measures involved, as well as the only variable to generate significant unique variance in predicting reading comprehension. Overall, there is still reason to believe that individual differences in retrieval ability contribute to the relationship between working memory and reading comprehension, however the role of long-term vocabulary knowledge needs to be considered further in regards to how these two constructs work together.

7.4 Theoretical and practical implications of the thesis

The current thesis took the adult dual-memory framework as a basis for examining the underlying processes that contribute to working memory, and how this develops through childhood. This was used as a tool to determine the extent to which children have access to different types of memory representations in different states. The novelty of the dual-memory framework is the proposal of two functionally distinct components that independently contribute to WMC. The current thesis sought to take the dual-memory framework and dissect the two components to examine whether it could be applied to help answer the broader theoretical question of how WMC develops through childhood.

This thesis has shown the importance of investigating the processes that underpin the development of WMC. There were two points of access for memory representations that facilitate working memory performance: the immediate access of actively maintained memory items in PM and the contextual, cue-dependent search processes attributed to SM. The thesis demonstrated that children were able to show the use of both cognitive constructs. However, the development of the independent processes seemingly developed at different rates. Despite being at a smaller capacity to what is described in the adult framework, children are able to access immediate information, actively maintained in PM. The use of this system becomes finely tuned through childhood, with children demonstrating more efficient allocation of attention and larger PM capacities. In contrast, children's use of SM was very limited and even at the age of ten years, they were unable able to show effective use of search and retrieval processes without the provision of explicit, external cues. Therefore, childrens dependency on the active maintenance of a fixed number of items reflects a different functional architecture of PM and SM use when compared to the adult framework.

PM and SM are described as two domain-general mechanisms (Chein et al., 2011) that follows on from the controlled attention view of working memory (Engle et al., 1999). PM representations are maintained by the allocation of attention (which can be selective or divided), despite qualitative differences in memory representations. The descriptions and evidence regarding PM resonates with the attentional demands commanded by the central executive (Baddeley, 2010, 2012) of the multi-component working memory model (Baddeley, 1986; Baddeley & Hitch, 1974) and Engle et al's domain-general attentional control system, associated with this specific component of the model. However, the components of PM and SM combine attentional control and basic memory abilities (Unsworth & Engle, 2007b). Therefore, despite demonstrating a domain-general attentional resource, there is still the possibility that PM may rely on domain-specific stores, such as the phonological loop and the visuospatial sketchpad or separate working memory systems to accommodate verbal and visual information (e.g. Shah & Miyake, 1996).

It also needs to be considered that short-term memory sub-systems are possibly not entirely discrete and information stored in separate modalities are linked (Darling et al., 2014), synonymous with the episodic buffer. This also brings into question the role of long-term memory and its contribution to the working memory system. This is another component of the traditional model that is not considered within the dual-memory model, but could help explain differences in the recall of single auditory and visual memory representations as well as dual memory representations. The extent to which SM was portrayed as a domain-general mechanism was not specifically explored within this thesis. From a developmental perspective it was more valuable to determine whether it was possible to observe when children began to systematically access information, using this specific cognitive construct. The next step is to assess the domain-specificity of the memory representations from a longer-term store.

At a broader level, this thesis provides the first lines of investigation and insight into the dual-memory framework from a developmental perspective. Future research needs to address key questions that will further support the use of PM and SM as tools to investigate the development of WMC. Firstly, based on the knowledge that SM develops at a slower rate than PM, it needs to be investigated at which stage children start to systematically retrieve information from SM. Within this, researchers need to consider when children are able to generate effective internal cues that efficiently delimit the search set within SM, enabling accurate retrieval from a longer term store. Secondly, by tracking the developmental use of PM and SM, it can be ascertained at which stage the two cognitive constructs become independent of one another. Finally, it should be addressed how the two constructs contribute to higher order cognitive processes such as fluid intelligence which has been established within the adult literature.

7.5 Strengths and limitations of the thesis

This thesis compared adults' and children's performance to determine consistencies and differences in the use of active maintenance through the allocation of attention and more demanding contextual search and retrieval processes to access information in working memory. The aim of this was to provide an overview of a life-span perspective of WMC. However, in order to accommodate the differing levels of cognitive development, tasks were made appropriate for the youngest five- to six-year old children. By implementing this, the tasks were probably too easy for adults, questioning whether their performance can actually be attributed to the PM and SM processes being measured in children. For example, the adult PM estimates predicted more unique variance than their SM estimates, which was not expected and does not converge with the children's pattern of performance or the adult dual-memory framework. The listening span task used in all experiments were designed for children, using stimuli and list lengths appropriate for children aged five- to ten-years of age. This may mean that adults did not need to displace items into SM, as the demands of the task meant it could all be carried out in immediate memory. Therefore, it would perhaps be expected that their WMC was driven by PM, as it was not necessary for them to use SM. However, correlational analyses carried out controlling for age did not show huge reductions in the inter-relations between measures, thus suggesting that adults were not completing the tasks and using underlying processes in a dissimilar manner to children. Future work needs to consider using an adult appropriate complex span task to determine whether this can explain the unique contributions of PM and SM demonstrated in the current work.

By comparing adults' and children's memory abilities, the thesis may be criticised for using narrow age ranges. In Experiments 1 and 2, children were aged five- to eight-years of age, which expanded to ten-year olds in Experiments 3 and 4. But this was reduced again to seven- to ten-year olds in Experiment 5. To provide a full developmental perspective, a wider age range needs to be tested on all the tasks adopted. This will help determine the point at which children show adult patterns of both PM and SM use and determine the supposed different developmental rates of the two independent domain-general mechanisms. However, this is followed by practical issues. Firstly, the experimenter had relatively limited access to visiting schools and the recruitment of children. In addition to this, some age groups were unavailable to work with due to curriculum constraints (e.g. SATs in Year 6). Secondly, there is the issue of study time constraints. If a more continuous range of children had been tested it may have not been possible to carry out all five experiments, thus limiting the scope of the thesis.

The broad objectives of this thesis meant that experiments have focused on experimental manipulations. Therefore, specific, detailed follow up experiments and fine-grained analyses were beyond the scope of the thesis. The novel, age-appropriate stimuli and tasks introduced in this thesis have been preliminarily investigated and established whether they are tapping into the accessibility of memory representations in children's working memory. Specific and detailed follow up experiments are now necessary and an individual differences approach can be applied to determine how differences in children's WMC are mediated by the attentional control and basic memory abilities that contribute to working memory performance.

A strength of the thesis was the design and implementation of independent tasks to ascertain the processes and cognitive profiles of the specific memory systems in adults and children. It was expected that consistencies in PM and SM estimates would be evident to provide confidence in the measurement of truly unitary constructs. However, this was not the case. The SIITs did not provide equivalent PM estimates when compared to the free recall data, despite both tasks measuring the same construct. An alternative argument to this weakness is the fact that the two different PM tasks were measuring two different signatures of the PM profile. The SIIT addressed the active maintenance of memory items in the face of distraction, whilst the free recall task indicated maximum PM capacity when unloading new, incoming information from the environment. As previously expressed, PM is not a static system and therefore, different capacities are a reflection of its flexibility as a cognitive mechanism. The re-use of the delayed cued recall task in Experiment 5 showed lower levels of recall. This was accompanied by no differences between Years 3 and 5 in the task under question and the conceptual span task, which had not occurred throughout the previous experiments. One potential explanation was the use of different schools. It is always attempted to maintain equivalent sampling distributions to enable the direct comparison of performances across experiments, however, in this case it may not have been achieved.

The implementation of the suggestions above, would provide a more thorough, detailed understanding of how the processes that underlie PM and SM develop in children and their contribution to WMC. To further establish whether the cognitive concepts of PM and SM can be applied to a developmental perspective, factor-analytic approaches could be considered as a future direction. By taking the novel measures used in this thesis with other potential measures, such as those used by Hall et al. (2015), and measures of attentional control, the collection of a lot more data points can be analysed. This would determine which groups of measures inter-collate with each other, but not with other sets of variables. This would accompany adult models that have already been generated (e.g. Unsworth et al., 2010) and would help understand the underlying structure of how adults and children use PM and SM, and specifically the interdependence of the two cognitive structures and their contribution to WMC.

7.6 Concluding remarks

This thesis has married theoretical perspectives on the multiple processes that underlie WMC and empirical research investigating qualitative and quantitative differences between adults and children and their focus during recall. Prior to this, no research had investigated the combined active maintenance of items in PM and retrieval processes from SM as independent contributions to the development of WMC. The thesis has discussed the conceptual and empirical potential of several new child-appropriate paradigms that compliment the underlying processes being investigated. It has been demonstrated that children are reliant on recency based recall strategies, reflective of a dependency on the active maintenance of items in working memory. This was accounted for by demonstrating how difficult it was for children to access information outside of conscious awareness. It was evident that SM items were accessible when external support was provided, suggesting children suffered from inefficient retrieval abilities, in order to recall target memory representations from working memory. Nonetheless, SM was a greater predictor of WMC than PM. Overall, this thesis has refined our understanding of how children use working memory as an interface to process information from our complex environment.

References

Alloway, T. P., Gathercole, S. E., and Pickering, S. J. (2006). Verbal and visuospatial short-term and working memory in children: are they separable? *Child Development*, 77(6):1698–716.

Atkinson, R., and Shiffrin, R. (1968). Human memory: a proposed system and its control processes. *Psychology of Learning and Motivation*, 2:89–195.

Atkinson, R., and Shiffrin, R. (1971). The control of short-term memory. *Scientific American*, 225(2):82–90.

Baddeley, A. (2000). The episodic buffer: a new component of working memory? *Trends in Cognitive Sciences*, 4(11):417–423.

Baddeley, A. D. (1986). *Working Memory*. Oxford, England: Oxford University Press.

Baddeley, A. D. (2007). *Working Memory, Thought and Action*. Oxford University Press.

Baddeley, A. D. (2010). Working memory. *Current Biology*, 20(4):R136–R140.

Baddeley, A. D. (2012). Working memory: theories, models and contraversies. *The Annual Review of Psychology*, 63(1):1–29.

Baddeley, A. D., and Hitch, G. J. (1974). Working Memory. In Bower, G., editor, *Psychology of Learning and Motivation: Advances in Research and Theory*, volume 8, pages 47–89. New York: Academic Press.

Bast, J., and Reitsma, P. (1998). Analyzing the development of individual differences in terms of matthew effects in reading: results from a dutch longitudinal study. *Developmental Psychology*, 34:1373–1399.

Bayliss, D. M., Jarrold, C., Gunn, D. M., and Baddeley, A. D. (2003). The complexities of complex span: explaining individual differences in working memory in children and adults. *Journal of Experimental Psychology: General*, 132(1):71–92.

Beaman, C. (2002). Inverting the modality effect in serial recall. *The Quarterly Journal of Experimental Psychology*, 55A(2):371–389.

Beaman, C., and Morton, J. (2000). The separate but related origins of the recency effect and the modality effect in free recall. *Cognition*, 77(3):B59–B65.

Bernbach, H. (1967). The effect of labels on short-term memory for colours with nursery school children. *Psychonomic Science*, 7(4):149–150.

Bhatarah, P., Ward, G., and Tan, L. (2006). Examining the relationship between free recall and immediate serial recall: the effect of concurrent task performance. *Journal of Experimental Psychology. Learning, Memory, and Cognition*, 32(2):215–29.

Bjork, R. A., and Whitten, W. B. (1974). Recency-sensitive retrieval processes in long-term free recall. *Cognitive Psychology*, 6:173–189.

Broadbent, D. (1958). *Perception and Communication*. London:Pergamon Press.

Brodie, D. A., and Murdock, B. B. (1977). Effect of presentation time on nominal and functional serial-position curves of free recall. *Journal of Verbal Learning and Verbal Behavior*, 16(2):185–200.

Brown, G. D. A., Preece, T., and Hulme, C. (2000). Oscillator-based memory for serial order. *Psychological Review*, 107:127–181.

Bryden, M. (1971). Attentional strategies and short-term memory in dichotic listening. *Cognitive Psychology*, 2:99–116.

Cain, K., Oakhill, J., and Bryant, P. (2004). Children's reading comprehension ability: concurrent prediction by working memory, verbal ability, and component skills. *Journal of Educational Psychology*, 96(1):31–42.

Carroll, J. B. (1993). *Human cognitive abilities: a survey of factor-analytic studies*. New York: Cambridge University Press.

Case, R., Kurland, D., and Goldberg, J. (1982). Operational efficiency and the growth of short-term memory span. *Journal of Experimental Child Psychology*, 33(3):386–404.

Chein, J. M., Moore, A. B., and Conway, A. R. A. (2011). Domain-general mechanisms of complex working memory span. *Neuroimage*, 54:550–559.

Cherry, E. C. (1953). Some experiments on the recognition of speech, with one and with two ears. *Journal of the Acoustical Society of America*, 25:975–979.

Cole, M., Frankel, F., and Sharp, D. (1971). Development of free recall learning in children. *Developmental Psychology*, 4(2):109–123.

Colflesh, G. J. H., and Conway, A. R. A. (2007). Individual differences in working memory capacity and divided attention in dichotic listening. *Psychonomic Bulletin & Review*, 14(4):699–703.

Conrad, R. and Hull, A. J. (1968). Input modality and the serial position curve in short-term memory. *Psychonomic Science*, 10(4):135–136.

Conway, A., Kane, M., Bunting, M., Hambrick, D., Wilhelm, O., and Engle, R. W. (2005). Working memory span tasks: A methodological review and user's guide. *Psychonomic Bulletin & Review*, 12(5):769–786.

Conway, A. R. A., Cowan, N., and Bunting, M. F. (2001). The cocktail party phenomenon revisited: The importance of working memory capacity. *Psychonomic Bulletin & Review*, 8(2):331–335.

Cowan, N. (1995). *Attention and memory: an integrated framework*. Oxford: Oxford University Press.

Cowan, N. (1999). An embedded-processes model of working memory. In Miyake, A. and Shah, P., editors, *Models of Working Memory: Mechanisms of Active Maintennace and Executive Control*, pages 62–101. New York: Cambridge University Press.

Cowan, N. (2001). The magical number 4 in short-term memory: a reconsideration of mental storage capacity. *The Behavioral and Brain Sciences*, 24(1):87–185.

Cowan, N. (2005). *Handbook of Understanding and Measuring Intelligence*. Sage Publications.

Cowan, N. (2008). What are the differences between long-term, short-term and working memory? *Progressive Brain Research*, 169:323–338.

Cowan, N., AuBuchon, A. M., Gilchrist, A. L., Ricker, T. J., and Saults, J. S. (2011). Age differences in visual working memory capacity: not based on encoding limitations. *Developmental Science*, 14(5):1066–74.

Cowan, N., Elliott, E. M., Scott Saults, J., Morey, C. C., Mattox, S., Hismjatullina, A., and Conway, A. R. A. (2005). On the capacity of attention: its estimation and its role in working memory and cognitive aptitudes. *Cognitive Psychology*, 51(1):42–100.

Cowan, N., Fristoe, N. M., Elliott, E. M., Brunner, R. P., and Saults, J. S. (2006). Scope of attention, control of attention, and intelligence in children and adults. *Memory & Cognition*, 34(8):1754–1768.

Cowan, N., Morey, C. C., AuBuchon, A. M., Zwilling, C. E., and Gilchrist, A. L. (2010). Seven-year-olds allocate attention like adults unless working memory is overloaded. *Developmental Science*, 13(1):120–33.

Cowan, N., Nugent, L. D., Elliott, E. M., Ponomarev, I., and Saults, J. S. (1999). The role of attention in the development of short-term memory: age differences in the verbal span of apprehension. *Child Development*, 70(5):1082–1097.

Cowan, N., Rouder, J. N., Blume, C. L., and Saults, J. S. (2012). Models of verbal working memory capacity: what does it take for them to work? *Psychological Review*, 119(3):480–499.

Cowan, N., Saults, J., Elliott, E. M., and Moreno, M. V. (2002). Deconfounding serial recall. *Journal of Memory and Language*, 46(1):153–177.

Cowan, N., Towse, J. N., Hamilton, Z., Saults, J. S., Elliott, E. M., Lacey, J. F., Moreno, M. V., and Hitch, G. J. (2003). Children's working-memory processes: A response-timing analysis. *Journal of Experimental Psychology: General*, 132(1):113–132.

Craik, F. I. M. (1969). Modality effects in short-term storage. *Journal of Verbal Learning and Verbal Behavior*, 4(1966):658–664.

Craik, F. I. M. (1971). Primary memory. *British Medical Bulletin*, 27(3):232–236.

Craik, F. I. M., Govani, R., Naveh-Benjamin, M., and Anderson, N. (1996). The effects of divided attention on encoding and retrieval processes in human memory. *Journal of Experimental Psychology: General*, 125(2):159–180.

Craik, F. I. M., and Levy, B. A. L. (1970). Semantic and acoustic information in primary memory. *Journal of Experimental Psychology*, 86(1):77–82.

Craik, F. I. M., and Lockhart, R. S. (1972). Levels of processing: a framework for memory research. *Journal of Verbal Learning and Verbal Behavior*, 11:761–784.

Cuvo, A. (1974). Incentive level influence on over rehearsal and free recall as a function of age. *Paper presented at the Annual Meeting of the Americam Psychological Association*.

Dalezman, J. (1976). Effects of output order on immediate, delayed, and final recall performance. *Journal of Experimental Psychology: Human Learning and Memory*, 2(5):597–608.

Daneman, M., and Carpenter, P. (1980). Individual differences in working memory and reading. *Journal of Verbal Learning and Verbal Behavior*, 466:450–466.

Daneman, M., and Merikle, P. (1996). Working memory and language comprehension: a meta-analysis. *Psychonomic Bulletin & Review*, 3(4):422–433.

Darling, S., Parker, M.-J., Goodall, KE; Havelka, J., and Allen, R. (2014). Visuospatial bootstrapping: implicit binding of verbal working memory to visuospatial representations in children and adults. *Journal of Experimental Child Psychology*, 119:112–119.

De Alwis, D., Myerson, J., Hershey, T., and Hale, S. (2009). Children's higher order cognitive abilities and the development of secondary memory. *Psychonomic Bulletin & Review*, 16(5):925–930.

Dempster, F. N. (1981). Memory span: sources of individual and developmental differences. *Psychological Bulletin*, 89:63–100.

Dempster, F. N., and Rohwer, W. D. (1983). Age differences and modality effects in immediate and final free recall. *Child Development*, 54(1):30.

Doyle, A. (1973). Listening to distraction: a developmental study of selective attention. *Journal of Experimental Child Psychology*, 15:100–115.

Dunn, L. M., and Dunn, D. M. (2009). *British Picture Vocabulary Scale - 3*. London: GL Assessment Ltd, 3rd edition.

Engel de Abreu, P. M., Conway, A. R., and Gathercole, S. E. (2010). Working memory and fluid intelligence in young children. *Intelligence*, 38(6):552–561.

Engle, R. W., Carullo, J., and Collins, K. (1991). Individual differences in working memory for comprehension and following directions. *Journal of Educational Research*, 84:253–262.

Engle, R. W., and Kane, M. J. (2004). Executive attention, working memory capaciy, and a two-factor theory of cognitive control. In Ross, B., editor, *The Psychology of Learning and Motivation*, volume 44, pages 145–199. NY: Elsevier.

Engle, R. W., Tuholski, S. W., Laughlin, J. E., and Conway, A. R. A. (1999). Working memory, short-term memory, and general fluid intelligence: a latent-variable approach. *Journal of Experimental Psychology: General*, 128(3):309–331.

Ericsson, K. A., and Kintsch, W. (1995). Long-term working memory. *Psychological Review*, 102:211–245.

Flavell, J., Beach, D., and Chinsky, J. (1966). Spontaneous verbal rehearsal in a memory task as a function of age. *Child Development*, 37(2):283–299.

Florit, E., Roch, M., Altoé, G., and Levorato, M. C. (2009). Listening comprehension in preschoolers: the role of memory. *British Journal of Developmental Psychology*, 27:935–951.

Foos, P. W., Sabol, M. A., Corral, G., and Mobley, L. (1987). Age differences in primary and secondary memory. *Bulletin of the Psychonomic Society*, 25(3):159–160.

Gathercole, S. E. (1999). Cognitive approaches to the development of short-term memory. *Trends in Cognitive Sciences*, 3:410–419.

Gathercole, S. E., and Adams, A.-M. (1993). Phonological working memory in very young children. *Developmental Psychology*, 29:770–778.

Gathercole, S. E., Adams, A.-M., and Hitch, G. J. (1994). Do young children rehearse? An individual-differences analysis. *Memory & Cognition*, 22(2):201–207.

Gathercole, S. E., Pickering, S. J., Ambridge, B., and Wearing, H. (2004). The structure of working memory from 4 to 15 years of age. *Developmental Psychology*, 40:177–190.

Geffen, G., and Sexton, M. A. (1978). The development of auditory strategies of attention. *Developmental Psychology*, 14(1):11–17.

Gibson, B. S., Gondoli, D. M., Flies, A. C., Dobrzenski, B. A., and Unsworth, N. (2010). Application of the dual-component model of working memory to ADHD. *Child Neuropsychology*, 16:60–79.

Gibson, B. S., Gondoli, D. M., Johnson, A. C., Steeger, C. M., Dobrzenski, B. A., and Morrissey, R. A. (2011). Component analysis of verbal versus spatial working memory training in adolescents with ADHD: a randomized, controlled trial. *Child Neuropsychology*, 17(6):546–63.

Gibson, B. S., Gondoli, D. M., Kronenberger, W. G., Johnson, A. C., Steeger, C. M., and Morrissey, R. A. (2013). Exploration of an adaptive training regimen that can target the secondary memory component of working memory capacity. *Memory & Cognition*, 41(5):726–37.

Gibson, B. S., Kronenberger, W. G., Gondoli, D. M., Johnson, A. C., Morrissey, R. A., and Steeger, C. M. (2012). Component analysis of simple span vs. complex span adaptive working memory exercises: a randomized, controlled trial. *Journal of Applied Research in Memory and Cognition*, 1:179–184.

Glanzer, M., and Cunitz, A. (1966). Two storage mechanisms in free recall. *Journal of Verbal Learning and Verbal Behavior*, 5:351–360.

Glenberg, A., Bradley, M., Stevenson, J., Kraus, T., Tkachuk, M., Gretz, A., Fish, J., and Turpin, B. (1980). A two-process account of long-term serial position effects. *Journal of Experimental Psychology: Human Learning and Memory*, 6(4):355–369.

Gomes, H., Molholm, S., Christodoulous, C., Ritter, W., and Cowan, N. (2000). The development of auditory attention in children. *Frontiers in Bioscience*, 5:108–120.

Guez, J., and Naveh-Benjamin, M. (2006). Divided attention at encoding and retrieval for once- and thrice-presented items: a micro-level analysis of attentional costs. *European Journal of Cognitive Psychology*, 18(6):874–898.

Haarmann, H., Davelaar, E., and Usher, M. (2003). Individual differences in semantic short-term memory capacity and reading comprehension. *Journal of Memory and Language*, 48:320–345.

Hagen, J. W. (1967). The effect of distraction on selective attention. *Child Development*, 38(3):685–694.

Hall, D., Jarrold, C., Towse, J. N., and Zarandi, A. L. (2015). The developmental influence of primary memory capacity on working memory and academic achievement. *Developmental Psychology*.

Hallahan, D. P., Kauffman, J. M., and Ball, D. W. (1974). Developmental trends in recall of central and incidental auditory material. *Journal of Experimental Child Psychology*, 17(3):409–421.

Hasher, L., and Clifton, D. (1974). A developmental study of attribute encoding in free recall. *Journal of Experimental Child Psychology*, 17:332–346.

Hasher, L., Lustig, C., and Zacks, R. T. (2007). Inhibitory mechanisms and the control of attention. In Conway, A., Jarrold, C., Kane, M. J., Miyake, A., and Towse, J., editors, *Variation in Working Memory*, pages 227–249. New York: Oxford University Press.

Healey, M. K., and Miyake, A. (2009). The role of attention during retrieval in working-memory span: a dual-task study. *Quarterly Journal of Experimental Psychology*, 62(4):733–45.

Healy, A. F., and McNamara, D. S. (1996). Verbal learning and memory: does the modal model still work? *Annual Review of Psychology*, 47:143–172.

Hulme, C., Thomson, N., Muir, C., and Lawrence, A. (1984). Speech rate and the development of short-term memory span. *Journal of Experimental Child Psychology*, 38:241–253.

Jablonski, E. M. (1974). Free recall in children. *Psychological Bulletin*, 81(9):522–539.

James, W. (1890). *The Principles of Psychology*. New York: Holt.

Jarrold, C., Hall, D., Harvey, C. E., Tam, H., Towse, J. N., and Zarandi, A. L. (2015). What can we learn about immediate memory from the development of children's free recall? *Quarterly Journal of Experimental Psychology*, 68(9):1871–1894.

Jarrold, C., and Towse, J. (2006). Individual differences in working memory. *Neuroscience*, 139:39–50.

Just, M. A., and Carpenter, P. A. (1992). A capacity theory of comprehension: Individual differences in working memory. *Psychological Review*, 99(1):122–149.

Kane, M., and Engle, R. W . (2000). Working-memory capacity, proactive interference, and di- vided attention: limits on long-term memory retrieval. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 26(2):336–358.

Kane, M., and Miyake, T. (2007). The validity of "conceptual span" as a measure of working memory capacity. *Memory & Cognition*, 35(5):1136–1150.

Kane, M. J., and Engle, R. W. (2002). The role of prefrontal cortex in working-memory capac- ity, executive attention and general fluid intelligence: an individual-differences perspective. *Psychonomic Bulletin & Review*, 9(4):637–671.

Kane, M. J., and Engle, R. W. (2003). Working-memory capacity and the control of attention: the contributions of goal neglect, response competition, and task set to stroop interference. *Journal of Experimental Psychology: General*, 132:47–70.

Kane, M. J., Hambrick, D. Z., Tuholski, S. W., Wilhelm, O., Payne, T. W., and Engle, R. W. (2004). The generality of working memory capacity: a latent-variable approach to verbal and visuospatial memory span and reasoning. *Journal of Experimental Psychology: General*, 133:189–217.

Katz, L. (1968). The limited-capacity hypothesis: effects of sequence length and instructions in free recall. *Journal of Verbal Learning and Verbal Behavior*, 7:942–944.

Leather, C. V., and Henry, L. A. (1994). Working memory span phonological awareness tasks as predictors of early reading ability. *Journal of Experimental Child Psychology*, 58:88–111.

Madigan, S. (1971). Modality and recall order interactions in short-term memory for serial order. *Journal of Experimental Psychology*, 87(2):294–296.

Martin, M. (1978). Retention of attended and unattended auditorily and visually presented material. *Quarterly Journal of Experimental Psychology*, 30:187–200.

McLeod, P., and Posner, M. I. (1984). Priviledged loops from percept to act. In Bouma, H. and Bowhuis, D., editors, *Attention and Performance*, pages 55–66. Hillsdale, NJ: Lawrence Erlbaum Associates.

Metcalfe, J., and Sharpe, D. (1985). Ordering and reordering in the auditory and visual modal- ities. *Memory & Cognition*, 13(5):435–441.

Miller, G. (1956). The magical number seven, plus or minus two:some limits on our capacity for processing information. *Psychological Review*, 63(81-97).

Miyake, A. (2001). Individual differences in working memory: introduction to the special section. *Journal of Experimental Psychology: General*, 130(2):163–168.

Miyake, A., and Friedman, N. (2004). Where does the predictive power of the reading span test come from? *Paper Presented at the 45th Annual Meeting of the Psychonomic Society, Minneapolis.*

Miyake, A., and Shah, P. (1999). *Models of Working Memory: Mechanisms of Active Maintennace and Executive Control*. New York: Cambridge University Press.

Mogle, J. A., Lovett, B. J., Stawski, R. S., and Sliwinski, M. J. (2008). What's so special about working memory? *Psychological Science*, 19(11):1071–1078.

Morrison, C. M., Chappell, T. D., and Ellis, A. W. (1997). Age of acquisition norms for a large set of object names and their relation to adult estimates and other variables. *The Quarterly Journal of Experimental Psychology Section A: Human Experimental Psychology*, 50A(3):528–559.

Murdock, B. (1962). The serial position effect of free recall. *Journal of Experimental Psychology*, 64(5):482–488.

Murdock, B. B., and Walker, K. D. (1969). Modality effects in free recall. *Journal of Verbal Learning and Verbal Behavior*, 8:665–676.

Murray, D., and Roberts, B. (1968). Visual and auditory presentation, presentation rate, and short-term memory in children. *British Journal of Psychology*, 59(2):119–125.

Muter, V., Hulme, C., Snowling, M. J., and Stevenson, J. (2004). Phonemes, rimes, vocabulary, and grammatical skills as foundations of early reading development: evidence from a longitudinal study. *Developmental Psychology*, 40(5):665–81.

Nation, K., Adams, J. W., Bowyer-Crane, C. A., and Snowling, M. J. (1999). Working memory deficits in poor comprehenders reflect underlying language impairments. *Journal of Experimental Child Psychology*, 73(2):139–58.

Oberauer, K. (2002). Access to information in working memory: exploring the focus of attention. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 28:411–421.

Osaka, M., Nishizaki, Y., Komori, M., and Osaka, N. (2002). Effect of focus on verbal working memory: critical role of the focus word in reading. *Memory & Cognition*, 30(4):562–571.

Ouellette, G. P. (2006). What's meaning got to do with it: the role of vocabulary in word reading and reading comprehension. *Journal of Educational Psychology*, 98:554–566.

Overschelde, J. P. V., Rawson, K. A., and Dunlosky, J. (2004). Category norms: an updated and expanded version of the Battig and Montague (1969) norms q. *Journal of Memory and Language*, 50:289–335.

Parkinson, S. R. (1974). Variability and control in dichotic memory. *Journal of Experimental Psychology*, 102(1):67–80.

Penney, C. G. (1989). Modality effects and the structure of short-term verbal memory. *Memory & Cognition*, 17(4):398–422.

Pierce, J. W. (2007). Psychopy - psychophysics software in python. *Journal of Neuroscientific Methods*, 162(1-2):8–13.

Pierce, J. W. (2009). Generating stimuli for neuroscience using psychopy. *Frontiers in Neuroinformatics*, 2:10.

Postman, L., and Phillips, L. W. (1965). Short-term temporal changes in free recall. *Quarterly Journal of Experimental Psychology*, 17(2):132–138.

Raymond, B. (1969). Short-term storage and long-term storage in free recall. *Journal of Verbal Learning and Verbal Behavior*, 8(5):567–574.

Richardson, J. T. E. (1996). Evolving concepts of working memory. In Richardson, J. T. E., Engle, R. W., Hasher, L., Logie, R. H., Stoltzfus, E. R., and Zacks, R. T., editors, *Working Memory and Human Cognition*, pages 3–30. Oxford University Press, USA.

Rundus, D. (1971). Analysis of rehearsal processes in free recall. *Journal of Experimental Psychology*, 89(1):63–77.

Saito, S. (2006). Forgetting and interference in working memory span tests. *Paper presented at the 4th International Conference on Memory, Sydney, Australia*.

Saito, S., and Miyake, A. (2004). On the nature of forgetting and the processing-storage relationship in reading span performance. *Journal of Memory and Language*, 50:425–443.

Salamé, P., and Baddeley, A. (1982). Disruption of short-term memory by unattended speech : implications for the structure of working memory. *Journal of Verbal Learning and Verbal Behavior*, 21:150–164.

Schroeder, P. J., Copeland, D. E., and Bies-hernandez, N. J. (2012). The influence of story context on a working memory span task. *The Quarterly Journal of Experimental Psychology*, 65(3):488–500.

Sexton, M. A., and Geffen, G. (1979). Development of three strategies of attention in dichotic monitoring. *Developmental Psychology*, 15(3):299–310.

Shah, P., and Miyake, A. (1996). The separability of working memory resources for spatial thinking and language processing: an individual differences approach. *Journal of Experimental Psychology: General*, 125:4–27.

Shelton, J. T., Elliott, E. M., Matthews, R. A., Hill, B. D., and Gouvier, W. D. (2010). The relationships of working memory, secondary memory, and general fluid intelligence: working memory is special. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 36(3):813–20.

Shiffrin, R. (1970). Forgetting: trace erosion or retrieval failure? *Science*, 168:1601–1603.

Shiffrin, R., and Atkinson, R. (1969). Storage and retrieval processes in long-term memory. *Psychological Review*, 76(2):179–193.

Shipstead, Z., Lindsey, D. R., Marshall, R. L., and Engle, R. W. (2014). The mechanisms of working memory capacity: primary memory, secondary memory, and attention control. *Journal of Memory and Language*, 72:116–141.

Siegel, A. W., and Allik, J. P. (1973). A developmental study of visual and auditory short-term memory. *Journal of Verbal Learning and Verbal Behavior*, 12(4):409–418.

Snowling, M. J., Stothard, S. E., Clarke, P., Bowyer-Crane, C. A., Harrington, A., Truelove, E., and Hulme, C. (2009). *York Assessment of Reading for Comprehension*. London: GL Assessment Ltd.

Spitzer, T. M. (1976). The development of visual and auditory recall as a function of presentation and probe modalities, serial position, and series size. *Child Development*, 47:767–778.

St Clair-Thompson, H. (2012). Ascending versus randomised list lengths in working memory span tasks. *Journal of Cognitive Psychology*, 24(3):335–341.

Stothard, S. E., and Hulme, C. (1996). A comparison of reading comprehension and decoding difficulties in children. In Cornoldi, C. and Oakhill, J., editors, *Reading Comprehension*

Difficulties, Processes and Intervention, pages 93–112. Mahvah, NJL Lawrence Erlbaum Associates.

Swanson, H. L. (2008). Working memory and intelligence in children: what develops? *Journal of Educational Psychology*, 100:581–602.

Swanson, H. L., and Berninger, V. (1995). The role of working memory in skilled and less skilled readers' comprehension. *Intelligence*, 21:83–108.

Tan, L., and Ward, G. (2000). A recency-based account of the primacy effect in free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 26(6):1589–1625.

Thorndike, R. L. (1973). *Reading Comprehension Education in Fifteen Countries*. New York: John Wiley and Sons.

Threadgold, E. (2012). *The relationship between processing and memory in working memory*. PhD thesis, Lancaster University.

Thurm, A., and Glanzer, M. (1971). Free recall in children: long-term store vs short-term store. *Psychonimic Science*, 23:175–176.

Towse, J., Hitch, G. J., and Hutton, U. (2000). On the interpretation of working memory span in adults. *Memory & Cognition*, 28(3):341–348.

Towse, J., Hitch, G. J., and Hutton, U. (2002). On the nature of the relationship between processing activity and item retention in children. *Journal of Experimental Child Psychology*, 82:156–184.

Towse, J. N., Cowan, N., Hitch, G. J., and Horton, N. J. (2008a). The recall of information from working memory: insights from behavioural and chronometric perspectives *Experimental Psychology*, 55(6):371–383.

Towse, J. N., Cowan, N., Horton, N. J., and Whytock, S. (2008b). Task experience and children's working memory performance: a perspective from recall timing. *Developmental Psychology*, 44(3):695–706.

Towse, J. N., Hitch, G. J., Horton, N., and Harvey, K. (2010). Synergies between processing and memory in children's reading span. *Developmental Science*, 13(5):779–89.

Towse, J. N., Hitch, G. J., and Hutton, U. (1998a). A reevaluation of working memory capacity in children. *Journal of Memory and Language*, 39:195–217.

Towse, J. N., Hutton, U., and Hitch, G. J. (1998b). Grass is coloured...red? Further sentence completion norms for children during a working memory reading task. *Technical report CDRG3*, pages 1–26.

Tulving, E., and Colotla, V. A. (1970). Free recall of trilingual lists. *Cognitive Psychology*, 1:86–98.

Tulving, E., and Patterson, R. D. (1968). Functional units and retrieval processes in free recall. *Journal of Experimental Psychology*, 77(2):239–248.

Tulving, E., and Thomson, D. M. (1973). Encoding specificity and retrieval processes in episodic memory. *Psychological Review*, 80(5):352–373.

Unsworth, N. (2007). Individual differencnes in working memory capacity and episodic retrieval: examining the dynamics of delayed and continuous distractor free recall. *Journal of Experimental Psychology: Learning, Memory and Cognition*, 33(6):1020–1034.

Unsworth, N. (2009). Examining variation in working memory capacity and retrieval in cued recall. *Memory*, 17(4):386–96.

Unsworth, N. (2010). Interference control, working memory capacity, and cognitive abilities: A latent variable analysis. *Intelligence*, 38(2):255–267.

Unsworth, N., Brewer, G. A., and Spillers, G. J. (2011). Inter- and intra-individual variation in immediate free recall: an examination of serial position functions and recall initiation strategies. *Memory*, 19(1):67–82.

Unsworth, N., and Engle, R. W. (2006a). A temporal–contextual retrieval account of complex span: An analysis of errors. *Journal of Memory and Language*, 54(3):346–362.

Unsworth, N., and Engle, R. W. (2006b). Simple and complex memory spans and their relation to fluid abilities: Evidence from list-length effects. *Journal of Memory and Language*, 54(1):68–80.

Unsworth, N., and Engle, R. W. (2007a). On the division of short-term and working memory: an examination of simple and complex span and their relation to higher order abilities. *Psychological Bulletin*, 133(6):1038–66.

Unsworth, N., and Engle, R. W. (2007b). The nature of individual differences in working memory capacity: active maintenance in primary memory and controlled search from secondary memory. *Psychological Review*, 114(1):104–32.

Unsworth, N., and Engle, R. W. (2008). Speed and accuracy of accessing information in working memory: an individual differences investigation of focus switching. *Journal of experimental psychology: Learning, Memory, and Cognition*, 34(3):616–30.

Unsworth, N., Spillers, G. J., and Brewer, G. A. (2010). The contributions of primary and secondary memory to working memory capacity: an individual differences analysis of immediate free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 36(1):240–7.

Verhoeven, L., and van Leeuwe, J. (2008). Prediction of the developing of reading comprehension: a longitudinal study. *Applied Cognitive Psychology*, 22:407–423.

Ward, G. (2002). A recency-based account of the list length effect in free recall. *Memory & Cognition*, 30(6):885–892.

Ward, G., Tan, L., and Grenfell-Essam, R. (2010). Examining the relationship between free recall and immediate serial recall: the effects of list length and output order. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 36(5):1207–41.

Watkins, M. (1972). Locus of the modality effect in free recall. *Journal of Verbal Learning and Verbal Behavior*, 8:644–648.

Watkins, M. J. (1974). Concept and measurement of primary memory. *Psychological Bulletin*, 81(10):695–711.

Watkins, M. J. (1977). The intricacy of memory span. *Memory & cognition*, 5(5):529–34.

Waugh, N., and Norman, D. (1965). Primary memory. *Psychological Review*, 72(2):89–104.

Whitten, W. (1978). Output interference and long-term serial position effects. *Journal of Experimental Psychology: Human learning and Memory*, 4(6):685–692.

Wilson, M. D. (1988). The mrc psycholinguistic database: machine readable dictionary, version 2. *Behaviour Research Methods, Instrument & Computers*, 20:6–10.

Wilson, P. T., and Anderson, R. C. (1986). What they don't know will hurt them: the role of prior knowledge in comprehension. In Orasanu, J., editor, *Reading Comprehension: From Research to Practice*, pages 31–48. Hillsdale NJ: Lawrence Erlbaum.

Wixted, J. T., and Rohrer, D. (1993). Proactive interference and the dynamics of free recall. *Journal of Experimental Psychology: Learning, Memory, and Cognition*, 19(5):1024–1039.

Yuill, N. M., Oakhill, J. V., and Parkin, A. J. (1989). Working memory, comprehension ability and the resolution of text anomaly. *British Journal of Psychology*, 80:351–361.

Appendices

Appendix I: Stimulus pool for the free recall task, Experiment 1

List format	**Words used**
Practice	Vest, Lips, Waist, Plug, Cage, Troop, Road, trout
	Brush, Leek, Bat, Chain, Jet, Food, Cot, Trail, Bean, Well
eight-items, 1s	Ash, Jar, Dad, Wool, Back, Stripe, Flame, Bill
	Mole, Night, Hail, Milk, Tape, Coal, Bone, Pie
	Blade, Half, Beam, Page, Dog, Yacht, School, Clay
	Wood, Guard, Blood, Sleeve, Feast, Gas, Car, Drill
	Gate, Frame, Cheese, Wheat, Sauce, Rat, Coat, Skirt
	Cat, Tent, Pin, Men, Cloud, Drawers, Toast, Pan
10-items, 1s	Boy, Fox, Whale, Doll, Rug, Ball, Mouse, Worm, Kite, Veil
	Chin, Girl, Rod, Cap, Wad, Barn, Fridge, Box, Swing, Pram
	Beach, Hen, Comb, Rock, Top, Bath, Saw, Team, Yard, Trunk
	Elf, Bug, Peach, Dice, Thread, Purse, Case, Dart, Vine, Claw
	Ship, Deer, Plane, Shrub, Whirl, Jug, Net, Towel, Pet, Cross
	Goat, Knee, Shed, Toad, Torch, Pond, Bowl, Cup, Wound, Rope

List format	Words used
Practice	Straw, Vale, Prune, Slave, Corn, Vet, Beast, Pouch
	Sheet, Chick, Brain, Jaw, Priest, Mug, Lamb, Hill, Stream, Ear
Eight-items, 2s	Dish, Soil, Hare, Ewe, Tomb, Ape, Switch, Gang
	Cheek, Band, Lord, Flute, Staff, Fleece, Home, Bird
	Desk, Smile, Bull, Bear, Gold, Chalk, Man, Step
	Cliff, Scout, Hoof, Crook, Fat, Lead, Prong, Bloom
	Kilt, Globe, Pew, Latch, Fork, Note, Dent, Skunk
	Frost, Cue, Rung, Lap, Stew, Tail, Brook, Knight
Ten-items, 2s	Fly, Camp, Hair, Bread, Stove, Shop, Geese, Boot, Reed, Stoat
	Map, Tide, Ox, Elm, Babe, Germ, Lane, Paste, Fort, Porch
	Crypt, Heap, Flock, Sand, Line, Waste, Suit, Gulf, Brim, Scroll
	Stain, Base, Lad, Arch, Smoke, Fish, Rust, Ground, Fan, Hook
	Charm, Text, Male, Room, Oil, Date, Coach, Spike, Gift, Moth
	Bud, Dough, Inn, Ghost, Crew, Park, Stile, Fire, Bun, Till

Appendix II: Words collected from the pilot data that were not used in the stimuli selection

(over 50% recalled from participants)

Category		**Items recalled**	
Fruit	Apple	Banana	Orange
Percentage	85	55	55
Vegetables	Carrot		
Percentage	55		
Furniture	Chair	Table	
Percentage	100	65	
Transport	Car	Train	Bus
Percentage	95	75	50
Fish	Cod		
Percentage	50		
Body part	Arm	Leg	
Percentage	80	75	
Instrument	Piano		
Percentage	65		
Insect	Fly		
Percentage	50		
Jewellery	Necklace	Ring	
Percentage	80	70	
Colours	Red	Blue	
Percentage	70	80	
Sport	Football	Tennis	
Percentage	80	60	
Royalty	Queen	Prince	
Percentage	100	70	
Clothing	Trousers		
Percentage	50		
Footwear	Shoe		
Percentage	75		
Drink	Water		
Percentage	65		

Appendix III: Stimuli chosen for the delayed cued recall tasks

Children's Delayed Cued Recall Task	
Category	**Stimuli**
Animal	Zebra, Camel, Monkey
Insect	Slug, Butterfly
Transport	Motorbike, Lorry, Helicopter
Tool	Spanner, Hammer, Nail
Clothes	Waistcoat, Jacket
Weapon	Gun, Sword, Spear
Body Part	Eye, Hand, Toes
Stationary	Rubber, Pencil, Ruler
Musical Instrument	Horn, Recorder, Trombone
Reptile	Lizard, Newt, Snake
Bird	Peacock, Penguin
Fictional Character	Wizard, Mermaid, Fairy
Job	Nurse, Builder
Plant	Cactus, Flower,
Food	Toast, Pizza, Crisps
Household item	Iron, Carpet
Fruit	Apricot, Pineapple

Adults' Delayed Cued Recall Task Taken from Miyake and Friedman (2004)	
Semantic Category	**Stimuli List**
Cosmetic	Mascara, Chorus, Driveway
Snack	Doughnut, Garden Angel
Reading Material	Magasine, Rattle, Powder
Crime	Kidnap, Edge, Wedding
Snake	Viper, Tower, Coal
Room	Partner, Attic, Cream
Sport	Canal, Tennis, Dynamite
Metal	Karate, Brass, Drama
Dairy Product	Balloon, Yoghurt, Terrace
Flower	Fountain, Lilac, Wheelchair
Meat	Blanket, Railway, Venison
Spice	Feather, String, Paprika
Fabric	Heaven, Brick, Cashmere
Colour	Prison, Kettle, Maroon
Tree	Tunnel, Gift, Willow

Appendix IV: Sentences taken from Towse et al. (1998b) and the cues generated for the sentence- and word-cue conditions

Sentence	Target word	Cue-Sentence	Cue-Non Sentence
I like to eat fish and	Chips	Fish	Potatoes
A baker made a load of	Bread	Baker	Sandwich
I can see with my	Eyes	See	Face
A spider has eight	Legs	Spider	Arms
A house is made of	Bricks	House	Wall
A king wears a	Crown	King	Head
I can hear with my	Ears	Hear	Sound/Music
The number after two is	Three	Number	Triplet
I sat down on a	Chair	Sat	Table
A pig has a curly	Tail	Pig	Wagging
A bicycle has two	Wheels	Bicycle	Car
I wear socks on my	Feet	Socks	Shoes
A giraffe has a long	Neck	Giraffe	Scarf
I go to sleep in a	Bed	Sleep	Pillow
A postbox is coloured	Red	Postbox	Danger
Cars drive on the	Road	Cars	Traffic
I waved goodbye with my	Hands	Wave	Gloves
A duckling is a baby	Duck	Duckling	Pond
I wear a hat on my	Head	Hat	Body
The sun is in the	Sky	Sun	Blue
I ran and won the	Race	Won	Medal
Fishermen sail a fishing	Boat	Fishermen	Sail
A witch flies on a	Broom	Witch	Sweep
Grass is the colour	Green	Grass	Tree
Birds have wings to	Fly	Birds	Plane
I eat my dinner with a knife and	Fork	Dinner	Spoon
Ice cream is very	Cold	Ice cream	Hot
Sharks live in the	Sea	Sharks	Wave
A farmer lives on a	Farm	Farmer	Fields
If it rains I will get	Wet	Rain	Dry
Rockets fly in outer	Space	Rockets	Planets
The magician waved his magic	Wand	Magician	Fairy

I use a toothbrush to clean my	Teeth	Toothbrush	Mouth
When I am thirsty I have a	Drink	Thirsty	Juice
You can see the moon at	Night	Moon	Stars
The football team scored a	Goal	Football	Net
I tell the time with a wrist	Watch	Time	Clock
To make a snowman you need	Snow	Snowman	Flakes
Worms live under	Ground	Worms	Soil
I unlocked the door with a	Key	Door	Lock
A fireman helped put out the	Fire	Fireman	Hot
Everyday I comb my	Hair	Comb	Curls
I skip with a skipping	Rope	Skip	Knot
Wool comes from	Sheep	Wool	Lamb

Appendix V: Stimuli chosen for the conceptual span tasks

Adults' and Children's stimuli for the non-clustered conceptual span task	
Category	**Stimuli**
Fruit	Cherry, Grape, Plum, Pear, Strawberry, Lemon
Transport	Boat, Tractor, Van, Bicycle, Ship, Airplane
Body Part	Finger, Ear, Lips, Thumb, Nose, Foot
Musical Instrument	Drum, Violin, Guitar, Trumpet, Flute, Cello
Insect	Wasp, Snail, Beatle, Ladybird, Bee, Spider.
Drink	Coffee, Lemonade, Juice, Tea, Cola, Milk
Vegetable	Potato, Mushroom, Onion, Lettuce, Pumpkin, Peas
Building	School, House, Castle, Windmill, Tower, Office
Footwear	Sandals, Boot, Trainers, Wellies, Plimsols, Slippers
Toys	Frisbee, Jigsaw, Doll, Yo-yo, Lego, Teddy
Flowers	Tulip, Daisy, Lilly, Poppy, Bluebell, Daffodil
Job	Doctor, Teacher, Fireman, Dentist, Soldier, Baker
Furniture	Wardrobe, Bed, Sofa, Desk, Bookcase, Stool
Sports	Hockey, Netball, Rugby, Swimming, Cricket, Running
Sea Creatures	Shark, Whale, Tuna, Trout, Dolphin, Salmon
Household items	Toaster, Fridge, Bath, Oven, Kettle, Telephone
Birds	Parrot, Crow, Robin, Chicken, Eagle, Pigeon
Clothes	Dress, Jeans, Coat, Jumper, Skirt, Jumper

Stimuli for Adults' Clustered Conceptual Span Task

Category	Stimuli
Country	Canada, Germany, Italy, Mexico, England, Italy
Tool	Hammer, Wrench, Pliers, Nail, Ruler, Saw
Confectionary	Chocolate, Marshmallow, Toffee, Fudge, Liquorice, Candy
Baby animals	Chick, Puppy, Foal, Bunny, Calf, Piglet
Weather	Snow, Fog, Hail, Wind, Blizzard, Storm
Family Member	Brother, Nephew, Mother, Cousin, Daughter, Aunt
Shape	Circle, Square, Pentagon, Triangle, Hexagon, Rectangle
Geography	Mountain, River, Valley, Lake, Volcano, Ocean
Reading Material	Magasine, Textbook, Novel, Newspaper, Website, Comic
Weapon	Rifle, Dagger, Spear, Gun, Arrow, Bat
Dance	Salsa, Ballroom, Tango, Ballet, Waltz, Tap
Fictional Character	Monster, Witch, Troll, Fairy, Wizard, Goblin
Emotion	Happy, Bored, Angry, Sad, Tired, Fear
Reptile	Lizard, Crocodile, Newt, Alligator, Gecko, Chameleon
Herb	Basil, Parsley, Thyme, Pepper, Sage, Rosemary
Metal	Iron, Bronze, Tin, Copper, Brass, Steel
Fabric	Wool, Cotton, Silk, Velvet, Linen, Nylon
Tree	Sycamore, Fir, Oak, Willow, Cedar, Beech